DEFENSE SYSTEMS MANAGEMENT COLLEGE

SIMULATION BASED ACQUISITION: A NEW APPROACH

Report of the
Military Research Fellows
DSMC 1997-1998

Lieutenant Colonel Michael V. R. Johnson, Sr., USA

Lieutenant Colonel Mark F. McKeon, USMC

Lieutenant Colonel Terence R. Szanto, USAF

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DEFENSE SYS MGMT COLLEGE
ATTN: AS PR
9820 BELVOIR RD, STE G3
FT BELVOIR, VA 22060-5565

Telephone: (703) 805-4366
DSN: 655-4366
Fax: (703) 805-3726

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PREFACE

This study presents the combined efforts of three military Research Fellows, participating in an 11-month Defense Systems Management College Research Fellowship program, sponsored by the Under Secretary of Defense for Acquisition and Technology. In keeping with its role as the center for systems management education in the Department of Defense (DoD), the Defense Systems Management College (DSMC) conducts this annual fellowship program to research a subject of vital interest to the U.S. defense acquisition community.

To achieve program objectives, program managers have long been applying modeling and simulation (M&S) tools to efforts within the various stages of their programs. Recently, however, declining defense budgets have increased the pressure on the acquisition community to find cheaper ways to develop and field systems. Additionally, the rapid pace of changing world events demands that these material solutions get into the hands of the warfighter faster. To meet the increased challenge of budget and time constraints, many programs have radically changed the way they conduct business. These programs recognize the powerful increases in productivity and decreases in cost brought by M&S tools. Within these programs, program management looks to weave M&S applications across program phases and seeks to leverage the strengths of external M&S applications to efforts within their program. This new way of doing business, coupling rapid advances in simulation technology with process change, is fueling a new approach to how we acquire defense systems. This new approach is being termed Simulation Based Acquisition, or SBA.

Objective of Study

The objective of this book is to convince program managers that SBA is a smarter way of doing business. We will do this by defining SBA, explaining the strengths of SBA, and describing the forces that will encourage its use. Where possible, we highlight best practices and useful implementation guidance.

Within the DoD, there are a staggering number of variables that an acquisition program office must evaluate and analyze. There is an almost infinite number of possible applications of SBA activities within DoD acquisition programs. Where they apply, we present examples of commercial applications of SBA. Most, however, are narrowly focused and are of questionable general use to acquisition program offices. This is partly because acquisition programs within the DoD are unique in their complexity compared with many commercial enterprises. Systems that the DoD produces are usually composed of many varied sub-components that push the boundaries of technology. When these complex sub-components are brought together in the aggregate at the system level, the complexity of the program is compounded. We hope that this “round down range” will stimulate discussion and provide the mark from which to “adjust fire.”

Methodology

We conducted our research in four areas. First, we embarked on basic research and information collection while attending the 12-week residential Program for Management Development (PMD) course at the Harvard University Graduate School of Business. Second, we conducted an extensive search of the applicable literature. Third, we conducted interviews and attended briefings and conferences on Simulation Based Acquisition. Finally, we held two in-process reviews with students attending the DSMC Advanced Program Managersment Course (APMC), and with the DSMC faculty.

Our initial research began while we were at the Harvard Business School. There, we presented and discussed issues concerning SBA with faculty members and our fellow classmates. As our classmates (157 students from 38 countries) represented both U.S. and international companies, we gained truly global insights into a few of the topic areas. We were also fortunate to have a few classmates working for U.S. defense contractors, who provided valuable perspectives into government and industry interrelationships and model sharing. Our discussions centered on applicable business practices and answers to numerous questions raised by our research topic. For example, should program managers be provided incentives to design and develop models and simulations that allow for reuse and/or integration into other programs? Are there applicable business practices, or measures of success/metrics that could evaluate the effective use of a government program's modeling and simulation efforts? Where did they see technology going in the near future?

Our second area of research was a comprehensive literature review and Internet search covering the topical areas of modeling and simulation and Simulation Based Acquisition. A particularly useful area was the SBA Special Interest Group on the Defense Modeling and Simulation Office's World Wide Web home page (www.dmso.mil), which contains a lot of historical and current information on the subject, as well as up-to-date links to modeling and simulation organizations and groups which are active on the web.

Our third area of research, conducting interviews and attending briefings and conferences, provided most of our information. We broke our areas of emphasis into three categories: government, defense industry and commercial industry. To gain insight into government programmatic issues, we visited Service Acquisition Offices, acquisition and test organizations, newly formed program offices, and established program offices. We obtained an understanding of the defense industry's support to government programs through visits to corporation headquarters and contractor facilities. We visited commercial firms that have been making significant investments in simulation technology. In all, we conducted over 85 interviews (see Appendix B). Some interviews were as short as thirty minutes, while some lasted over the course of three days. Most, however, were three or four hours in duration. The level of the interviewees varied greatly, from Senior Acquisition Officials and Program Managers to individuals tasked with constructing physical wooden mock-ups (used in the verification of virtual models). Though the sources varied, there was a great deal of commonality in the views expressed. We also participated in and attended several SBA conferences and workshops. Each site visited provided unique insights into the collage that is the Simulation Based Acquisition picture.

Our final area of data collection was through peer and faculty review at DSMC. Through frank discussions conducted in our office spaces and the use of the DSMC's Management Deliberation Center (a Group Decision Support System), many of the APMC students provided us with an excellent sounding board on the direction and progress of our research. These in-process reviews helped ensure we were addressing the issues most important to the acquisition community concerning Simulation Based Acquisition.

Special Thanks

The Research Fellows extend a special note of appreciation to Ms. Joan Sable, DSMC Military Research Fellowship Coordinator. Ms. Sable ensured that our administrative and logistical requirements were met at DSMC and Harvard, and her support enabled us to concentrate our attention and energies on the research and writing of this report.

For all of their guidance throughout our research project we pay special thanks to Colonel Kenneth "Crash" Konwin, Director Defense Modeling and Simulation Office; Ms. Robin Frost, Office of the Secretary of Defense (Director of Test, Systems Engineering, and Evaluation); and Mr. Steve Olson and the other members of the National Defense Industrial Association's SBA Industry Steering Group.

We appreciate the efforts of the DSMC Press staff for their many hours working on this report to ensure its highest quality. Thanks to the Visual Arts and Press staff for their work on the graphs, charts and cover page as well as their many hours in the layout of this report. Finally, we extend a special thank you to Air Force Academy Cadets First Class Paul Ferguson and Nathan Atherley for their research assistance during their summer internship at DSMC.

There are others, too numerous to mention individually, who deserve recognition. The three Research Fellows would like to thank all of those interviewed. As a token of our appreciation, we dedicate this effort to you. May our report be as helpful to you as you were to us.

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INTRODUCTION

The Services and DoD are committed to provide superior weapon systems and materials to the warfighter faster, and at less cost. To achieve this, the acquisition community is charged with providing "better, faster, and cheaper" material solutions. Our research shows that the practices and processes of simulation based acquisition (SBA) will help overcome many of the hurdles associated with acquiring "better, faster, and cheaper" solutions.

The phrase "better, faster, and cheaper" is deceptively simple, because the execution of this task across the Services and DoD is a complex undertaking. As many program offices will attest, this statement rings true for three reasons. First, the current Government acquisition process, with its oversight requirements and the nature of its funding, is not the most streamlined or efficient of processes. Second, many large Government acquisition programs develop complex systems, which push the limits of technology. And third, program complexity is further magnified since most of the material solutions produced are not stand-alone products. That is, they are "force multipliers" that must interface with and enhance the combat performance of other systems that are either fielded or in development. Unlike many commercial programs, therefore, the current acquisition processes (indeed the very solutions themselves) are usually complicated.

To be successful, a program office must balance the complex relationships that exist between "better", "faster", and "cheaper." The degree of balance is not usually measured directly, but it can be measured in terms of the risk in meeting objectives. Risk is a measure of the inability to achieve a program's defined performance, schedule, and cost objectives. It has two components: the probability of failing to achieve particular performance, schedule, or cost objectives and the consequences of failing to achieve those objectives.[1] SBA can address the first component of risk by increasing the likelihood of producing systems that have "better" performance, "faster" schedule, and "cheaper" cost.

Better Performance

No one would advocate providing the warfighter with something that is "almost as good as." The material solutions that the U.S. defense acquisition community produces are the tools of victory on future battlefields. Finding and producing "better" solutions starts with the warfighter's ability to correctly articulate the requirement. This frames all of the acquisition activities that follow.

Concepts that satisfy stated requirements must then be identified and evaluated. The military has a much harder problem to solve than does the commercial automotive or aviation industries, since they usually have a good starting point. And while they produce some very complicated products, the basic concepts for commercial products do not deviate greatly from one generation to the next. Follow-on systems within the DoD, on the other hand, are usually radical departures from their predecessors. Take as an example, air superiority fighters; the F-22 can hardly be viewed as a variant of the F-15. The increased performance demanded of follow-on DoD systems brings with it the increased likelihood that these performance objectives will not be met.

Through the use of modeling and simulation, an SBA process offsets this increased performance risk in three ways. First, it enables the warfighter to become a member of the design team and to influence the design much earlier than the current process allows. Simulation provides the tools for the warfighter to visualize and interact with the system to perform operational analyses and assessments. The design team rapidly incorporates necessary changes into the design based upon this expert input and the result is a better solution. Second, the SBA process provides rapid feedback to the design team by enabling them to perform "what if" analyses, or iterations, on hundreds of point designs. Rather than building a physical prototype to validate a single point design, designers can use a virtual prototype to look at potentially hundreds of design variations. The rapid feedback and learning from these iterations will enable the program office to produce a better system. Third, not only are we able to conduct more iterations, but we are also able to converge on more optimal designs because we can test many of our assumptions to see if they are true. Furthermore, as the tools for looking at the entire life cycle of the system improve, design teams will be able to move from form and fit issues to the more complex issues of function. This, too, will contribute to better solutions.

Faster Schedule

The military goes to war with what is fielded, not with what is on the drawing boards or in the acquisition pipeline. As Lieutenant General Paul J. Kern, Director of the Army's Acquisition Corps stated, "The current acquisition process was good for producing systems in the Cold War environment, where we had a predictable enemy with known lead times. Now, many of our foreseeable potential enemies are different; they are not constrained by a rigid, inflexible acquisition process. They can purchase weapon systems and/or sub-components in an open-air market environment, like a global off-the-shelf system. Through mixing and matching various weapon systems and subsystems, they can rapidly generate some very lethal systems. We lose if they can purchase and bring together their systems faster than we can develop ours because of long cycle times."[2]

By enabling the acquisition process to get inside the adversary's decision cycle, an SBA process increases the likelihood of developing and producing systems "faster". If we can model what we need answers to, we can get rapid feedback through the power of simulation. The program gets the required information much sooner in the process than it does under the current system, translating into faster cycle times. Additionally, we can conduct many more processes concurrently because more people can access the information they need at the same time. Concurrent engineering activities within an SBA process will compress the cycle time of weapons acquisition. Working with virtual prototypes and digital product descriptions allows program managers to exhibit agility in designing and evaluating concepts. For example, using computational fluid dynamics, the test community can help the design team look at weapons release issues much earlier and at a fraction of the cost of running a wind tunnel test. Virtual manufacturing allows the manufacturing community to look at procedures such as reducing the number of parts in the design as well as rehearsing production processes. Using three-dimensional solid modeling, shop-floor mechanics can assess the maintainability of the design and make design inputs alongside the engineers, much earlier in the process.

Cheaper Cost

"Cheaper" can be broken down into two areas. The first area involves reducing the initial acquisition cost of systems. This point was illustrated by Norm Augustine two decades ago in one of his famous Augustine's Laws: "In the year 2054, the entire defense budget will purchase just one tactical aircraft. This aircraft will have to be shared between the Air Force and Navy 3 days each per week."[3] Clearly there's a need to reverse and stabilize the trend in rising initial acquisition costs. Second, "cheaper" also includes reducing the annual costs of operating and sustaining systems until and including disposal. The foreseeable trend in system life span is that DoD will be living with major systems for longer periods of time. As systems get older, the sustainment costs usually rise. To address concerns within these two areas, the Defense Systems Affordability Council, chaired by the Under Secretary of Defense for Acquisition and Technology, recently directed the establishment of ambitious top level goals for reducing total ownership cost.

Regarding the first area of reducing initial acquisition costs, an SBA process increases the likelihood that a program will stay within its cost objectives during the acquisition phase. The synthetic environment reduces the reliance on costly physical prototypes and tests for making programmatic decisions. Physical tests are primarily done to validate models and generate confidence in the use of the models. These validated models can then be reused to perform numerous design simulations, at a fraction of the cost of one physical test. Simulations also help to focus the test effort on the critical evaluation areas, thereby avoiding unnecessary physical tests. As noted by Air Force Major General Leslie Kenne, Program Manager for the Joint Strike Fighter aircraft, "We haven't begun to tap all the benefits that modeling and simulation has to offer to reduce our testing requirements."[4]

Regarding the second area of reducing sustainment costs, an SBA process increases the likelihood that a program can reduce the annual costs of operating and sustaining systems until and including disposal. Although it's difficult to find a definitive source for the data, it is frequently mentioned that approximately 70 percent of the total costs of a system are determined by the time a new program receives approval to start (referred to as "Milestone I"), and 85 percent are determined by the time a program's design is selected (referred to as "Milestone II").[5] These early decisions, which directly affect total ownership cost, are currently being made with limited knowledge of system cost, schedule and performance implications. It is speculative at best to determine how much of a system's total ownership cost can be influenced by better design decisions. Certainly, however, as the ability to simulate the entire system's life cycle continues to improve, so too will the ability to make intelligent tradeoffs on how much to spend now in improvements in manufacturability, reliability, maintainability, and supportability in order to save later. A significant value of SBA is that it allows program offices to begin evaluating the long-term cost impacts of design decisions as part of the design process, rather than relying on engineering change proposals and modifications to fix the problem after the design is frozen.

Guide To This Report

Chapter Two, Definitions and Terminology, lays the foundation for the SBA Vision Statement and Definition that follow.

Chapter Three, Background, presents current policy and guidance, previous studies and conclusions, and some assumptions and trends upon which SBA depends upon.

Chapter Four, Essential Aspects of SBA, introduces the theoretical practices that support an SBA process.

Chapter Five, Expanding the SBA Envelope, identifies the forces that will generate progress towards implementing SBA. These include the forces internal to a program that will push SBA along, as well as the external pull from the warfighting and resource allocation communities.

Chapter Six, A Future State of SBA, develops a model and vision for what SBA can hope to achieve in the future, by identifying notional SBA components and their interactions.

Chapter Seven, Challenges to Implementing SBA, describes some of the challenges that a program may face as it tries to implement an SBA approach.

Chapter Eight, Conclusions and Recommendations, summarizes our conclusions about the prospects for implementing SBA, and provides our recommendations for making the transition to this new way of acquiring defense systems.

What we present throughout this report we have heard many times from many people. It is our hope that we have presented our research in such a way as their message comes across loud and clear and that you are convinced that SBA is a better way of doing business.

1. Defense Systems Management College, *Acquisition Strategy Guide, Third Edition,* (Fort Belvoir, VA: Defense Systems Management College Press, January 1998).

2. LTG Paul J. Kern, Military Deputy to Assistant Secretary, Army RD&A, interview with authors, 7 May 1998.

3. Norman R. Augustine, "Augustine's Laws and Major System Development Programs," Defense Systems Management Review, Volume 2, Number 2, p. 64.

4. Major General Leslie J. Kenne, Program Manager, Joint Strike Fighter Program, Remarks at the National Defense Industrial Association SBA Conference, 17 March 1998.

5. John Krouse. *Computer Aided Engineering, Onward Press,* June 1993, p. 7.

2

DEFINITIONS AND TERMINOLOGY

Many within the DoD, the Armed Forces, and industry realize the enormous potential of a Simulation Based Acquisition process, and SBA has recently been the topic of several conferences and workshops. There has been some disagreement and confusion, however, in getting to a common understanding of exactly what SBA is. Certainly SBA is a new way of doing business for acquiring DoD weapon systems, which implies a need to change our processes. And it has been described by the policy and cultural changes necessary to bring about this changed process, the favorable environment necessary to speed it along, as well as the technical impediments to its swift enactment. But what exactly is SBA?

M&S Definitions

First we need to clarify some terminology used throughout this book. (We highly recommend referring to DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary*, for current definitions in this fast changing area. It is available on-line on the DMSO World Wide Web Home page, mentioned previously in the Preface.) According to DoD 5000.59-M, a model is "a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process."[1] (Entities are "a distinguishable person, place, unit, thing, event, or concept about which information is kept."[2]) It is important to note that a model can exist without a single piece of software.[3] It can be a hardware mockup or a simple equation on a piece of paper. A simulation is "a method for implementing a model over time."[4] Thus, to tie the two together, simulations are the software that implements models over time, within the context of a scenario.[5]

A great deal of confusion often results from the common practice of using the terms "modeling" and "simulation" interchangeably, as well as that of using the term "M&S" to stand for both *models and simulations* and *modeling and simulation.*[6] In this report we use the term "M&S" to stand for modeling and simulation, which is an analytical problem-solving approach.[7] Modeling and simulation, as defined in the DoD M&S Glossary, is "the use of models, including emulators, prototypes, simulators, and stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions."[8]

Hierarchies and Classes of Models and Simulations

As shown in Figure 2-1, models and simulations have been classified hierarchically according to their level of aggregation. Aggregation is the ability to group entities, while preserving the effects of entity behavior and interaction when grouped.[9] The four general classifications are Engineering, Engagement, Mission/Battle, and Theater/Campaign.[10] Engineering models and simulations are at the least level of aggregation, whereas Theater/Campaign models and simulations are at the highest. Within these classifications, models and simulations can vary in their level of detail or representation.

- Engineering level models and simulations provide measures of performance (MOP) concerning such issues as design, cost, manufacturing, and supportability. They can include aerodynamics, fluid flow, acoustics, and fatigue, as well as physics-based models of components, subsystems, and systems.[11]

- Engagement level models and simulations are used for evaluating the effectiveness of an individual system against another system in one-on-one, few-on-few, and many-on-many scenarios. They provide measures of effectiveness (MOE) at the system-on-system level.[12]

- Mission/Battle level models and simulations are used for evaluating the effectiveness of a force package, or multiple platforms performing a specific mission. They provide MOE at the force-on-force level.[13]

- Theater/Campaign level models and simulations are used to evaluate the outcomes of joint and combined forces in a theater

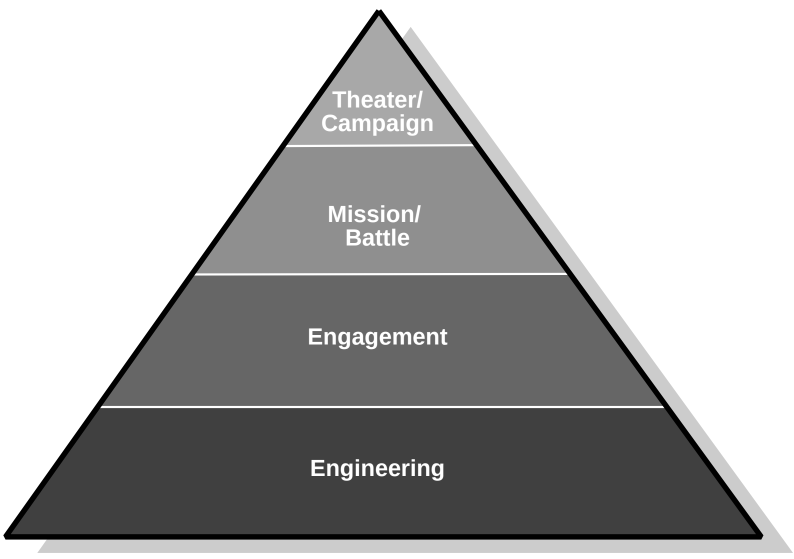


Figure 2-1. Hierarchies of Models and Simulations

or campaign level conflict. They provide measures of value (sometimes referred to as measures of outcome-MOO) at the highest levels of conflict.[14]

This classification of models and simulations is significant to acquisition programs, because the type of information required determines the level of aggregation to be used. Solutions to broad issues, such as mission need statements, can be explored with highly aggregated models and simulations. More focused issues, such as the maturing of the design, dictate that the models and simulations move towards and into the engineering category. Programs must, therefore, move up and down this ladder of abstraction to tailor the models and simulations to their needs. For example, highly aggregated simulations can explore the battlefield effects of increasing an aircraft's combat radius. If the results are promising, the design team could then use engineering level models and simulations to address the associated detailed design issues, such as increasing the aircraft's internal fuel capacity. There are also additional considerations for tailoring the level of aggregation, such as unnecessary computational burden and the complexity of information management.

Models and simulations have long been classified into the three classes of *Live*, *Virtual*, and *Constructive*, which attempt to delineate the degrees of human and equipment realism, as shown in the matrix in Figure 2.2.[15] *Live* simulations denotes real people operating real systems; *virtual* simulations denotes real people operating simulated systems; and *constructive* models and simulations denote simulated people operating simulated systems. Smart simulations denotes simulated people operating real equipment. The live, virtual and smart classes are applied to simulations, but not models since live models would be humans

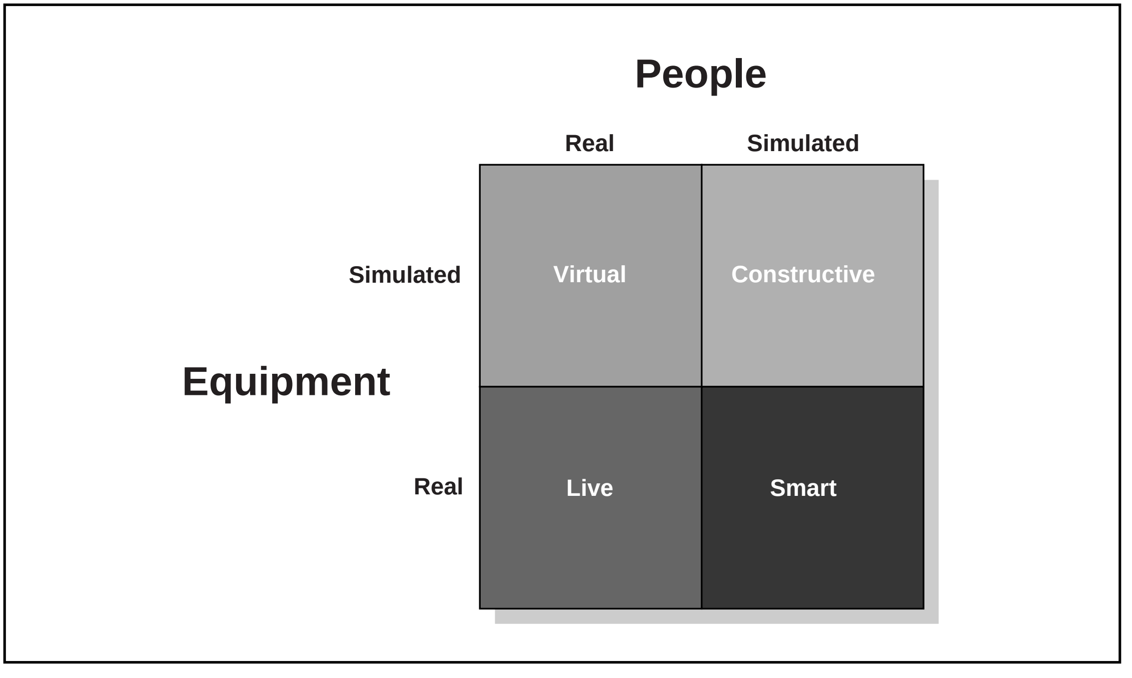


Figure 2-2. Matrix of Classes of Models and Simulations

and actual equipment. The term virtual model would be misleading since virtual simulations inject humans-in-the-loop to exercise motor control, decision making, or communications skills, and the human element of a virtual simulation is not modeled (the simulated systems in virtual simulations would be made up of constructive models). On the other hand, in constructive simulations, real people stimulate (make inputs) to the constructive models, but the people are not involved in determining the outcomes.[17] Hence it is appropriate to have both constructive models and constructive simulations.

As noted by the DoD M&S Glossary, the classification of live, virtual, and constructive can be somewhat problematic for two reasons. First, there is no clear delineation between the categories, because the degrees of human involvement and equipment realism are infinitely variable. The second reason it is a problematic classification is highlighted by the fact that the bottom right quadrant of Figure 2.2 has not been previously named to indicate the class of simulated people operating real equipment.[18] We have named this class of simulations as smart simulations.

There is value, however, in marrying the hierarchies and classes of models and simulations together, as shown in Figure 2-3, to show the range of possibilities when discussing M&S support to acquisition. Constructive models and simulations can range from highly aggregated, theater level models and simulations, to physics-based, engineering level models and simulations. This range of aggregation can be applied to virtual simulations, and we can envision the same for the obverse of virtual simulations (the “smart” classification). The possible combinations are wide-ranging, including such hybrid combinations as hardware/

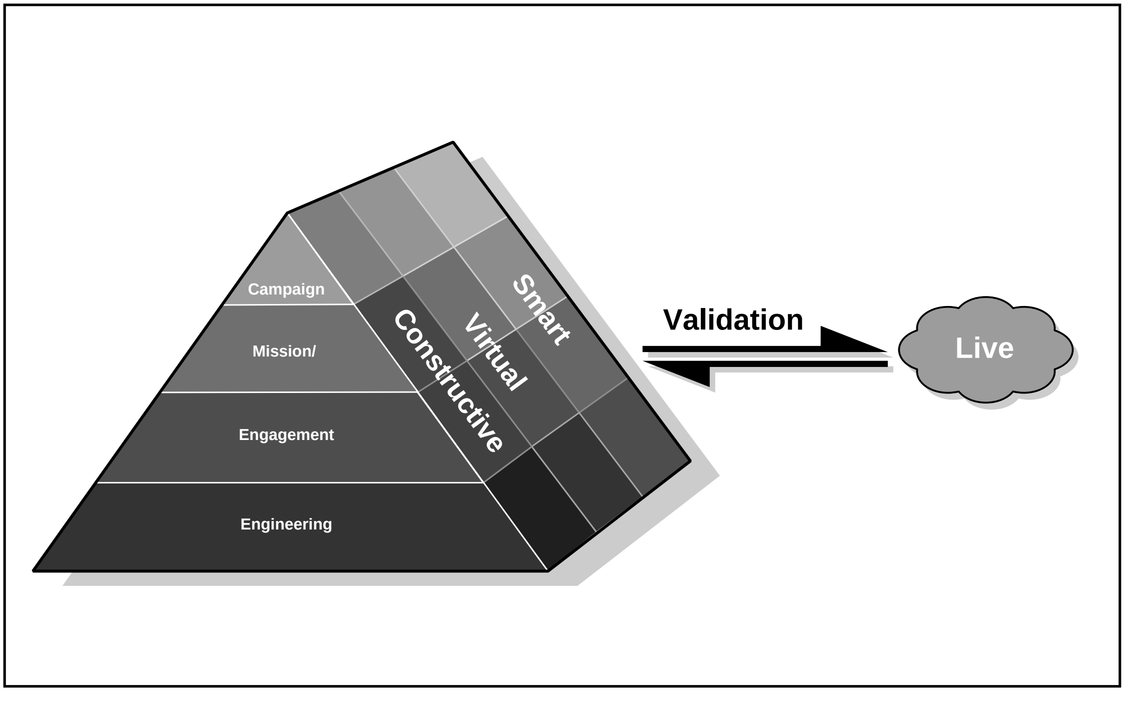


Figure 2-3. Hierarchies and Classes of Models and Simulations

software in the loop (HW/SWIL), human in the loop (HITL), and wargaming. It is not necessary to package every model or simulation into a particular category—the utility is in exploring the numerous possible hybrid combinations available and tailoring them to the requirement.

While the classification of live simulation was useful for the training community, the concept of real people and real equipment takes on a different purpose for the acquisition environment. In the training vernacular of "all but war is simulation," real people and real equipment are still simulations of the real event of war. For the acquisition of systems, there are two roles for the classification of real people and real equipment. The first role is testing that which cannot be adequately depicted in the synthetic environment, because of insufficient knowledge or technology. The data obtained from these tests could be used for future model development. The second role is to validate the models and resultant simulations. The "live" events in these two roles can range from component level tests to large-scale physical prototypes, but in each case their purpose is to validate. The first role validates either a concept or design, whereas the second role validates a model or simulation.

Virtual and Synthetic

When discussing M&S and SBA, it is important to have a common understanding of the word "virtual." In the most general sense, virtual "refers to the essence or effect of something, not the fact."[19] In practice, the word virtual is usually paired with another word, as in virtual battlespace, virtual reality, and virtual prototype. Virtual battlespace is defined as "the illusion resulting from simulating the actual battlespace."[20] Virtual reality is "the effect created by generating an environment that does not exist in the real world. Usually, [virtual reality is] a stereoscopic display and computer-generated three-dimensional environment which has the effect of immersing the user in that environment. This is called the immersion effect. The environment is interactive, allowing the participant to look and navigate about the environment, enhancing the immersion effect. Virtual environment and virtual world are synonyms for virtual reality."[21] Synthetic environments, on the other hand, are defined as "... simulations that represent activities at a high level of realism, from simulations of theaters of war to factories and manufacturing processes. These environments may be created within a single computer or a vast distributed network connected by local and wide area networks and augmented by super-realistic special effects and accurate behavioral models. They allow visualization of and immersion into the environment being simulated."[22] Finally, virtual prototypes are "a model or simulation of a system placed in a synthetic environment, and are used to investigate and evaluate requirements, concepts, system design, testing, production, and sustainment of the system throughout its life cycle."[23]

Life Cycle Cost and Total Ownership Cost

The concepts of life cycle cost (LCC) and total ownership cost (TOC) also figure prominently when discussing SBA. The term TOC often appears to be replacing the term LCC. TOC is the totality of costs associated with the *Department of Defense*, including the costs related to weapon systems, whereas LCC is the totality of costs over time related to developing, acquiring, operating, supporting and disposing of *weapon systems*.[24] The Secretary of Defense, William S. Cohen, states in his *Annual Report to the President and the Congress* that "Total ownership cost is the sum of all financial resources necessary to organize, equip, and sustain military forces sufficient to meet national goals in compliance with all laws; all policies applicable to DoD; all standards in effect for readiness, safety, and quality of life; and all other official measures of performance for DoD and its components."[25] When viewed this way, LCC inherently refers to that subset of TOC that has to do with weapons systems.

In practice, however, TOC is often used in a weapon system context, in which case TOC and LCC appear to be synonymous terms, as they both cover all costs to research, develop, acquire, own, operate and dispose of a weapon system for a specific (or assumed) number of years. However, TOC as applied to weapon systems seems to imply a greater effort to capture more of the costs covered by both definitions than has heretofore been practiced routinely in DoD under the banner of LCC.[26] For example, if a new system or concept will require additional security forces as part of its operation, then the life cycle cost of this support would most likely be factored in to the TOC of the system or concept, but would probably not have been included under LCC. There are many on-going debates on this subject, which we don't intend to resolve here. In this book we use the more-encompassing term TOC.

SBA Vision Statement

For many years, the training community has leveraged the strengths of M&S to augment live training. As noted by General Richard Hawley, Commander of Air Combat Command, "…[M&S] has been a key part of our training for many years, but…we've never fully exploited the contributions that modeling and simulation can make to our readiness programs."[27] Similarly, although the acquisition community has also made M&S a key part of the systems acquisition process for many years, it too is beginning to realize that the benefits of M&S haven't been fully exploited. In his 16 March 1998 Memorandum, the Honorable Jacques S. Gansler, Under Secretary of Defense (Acquisition and Technology), stated, "As we undergo changes in our defense acquisition infrastructure, let me take this opportunity to firmly state my commitment to the use of M&S in the acquisition of our weapons systems…. Therefore, it is essential that we plan for the use of M&S in our acquisition strategies. I expect programs to make the upfront investment in M&S application and technology and will be looking for evidence of that investment in program planning and execution."[28] Dr. Gansler goes on to note additional steps he is endorsing for the SBA initiative to capitalize on the current efforts in M&S.

The DoD, in collaboration with industry, developed a vision statement for SBA that envisions an acquisition process in which DoD and industry are enabled by robust, collaborative use of simulation technology that is integrated across acquisition phases and programs. The goals of SBA are to:

1. Substantially reduce the time, resources, and risk associated with the entire acquisition process;

2. Increase the quality, military worth, and supportability of fielded systems, while reducing total ownership costs throughout the total life cycle; and

3. Enable Integrated Product and Process Development (IPPD) across the entire acquisition life cycle.[29]

SBA Definition

This vision statement promotes discussions about SBA, and most people basically agree with its intent. However, an expanded definition of SBA is instructive:

> Simulation Based Acquisition is an iterative, integrated product and process approach to acquisition, using modeling and simulation, that enables the warfighting, resource allocation, and acquisition communities to fulfill the warfighter's materiel needs, while maintaining Cost As an Independent Variable (CAIV) over the system's entire life cycle and within the DoD's system of systems.

A discussion of each of the definition's critical elements follows.

"Simulation Based Acquisition is an iterative, integrated product and process approach to acquisition": SBA enables Integrated Product and Process Development (IPPD) teams to converge on optimal solutions by balancing requirements through an iterative design process. DoD and contractor organizations work internally and with each other as an integrated team effort.[30] IPPD used to mean that we put a logistician on the design team to translate his maintenance and support knowledge into meaningful design guidelines. Now IPPD means arming the hands-on experts with the tools to rapidly see the results of their design inputs, thereby making them a part of the design team. For example, using three-dimensional "solid" models, the F-22 aircraft program enabled two mechanics to inject maintainability changes into the design tradeoffs, because they were able to visualize the system much earlier in the process.

"…through modeling and simulation": M&S activities make SBA possible. Stepping into the synthetic environment enables exercising the power of simulation. Within the same time frame, many more analytical excursions can be made with virtual designs than would be possible with physical prototypes. The increased level of user involvement, coupled with compressed time and space feedback, lead to better learning and problem solving. This is far superior to the traditional approach, which is driven by real experiences using physical prototypes.[31] M&S facilitates the team and increases communication, making team members more effective.

"…the warfighting, resource allocation, and acquisition communities": SBA is more than just acquisition. SBA helps to link the DoD's three principal decision support systems: the Requirements Generation System, the Planning Programming and Budgeting System, and the Acquisition Management System.[32] Figure 2-4 shows the relationship of these three communities. The name of the community representing the Requirements Generation System is changed to the more expansive term of warfighting community, which includes: requirements personnel, operators, maintainers/sustainers, and trainers. The resource allocation community is also an integral part of the acquisition process, as it allocates the program budgets (subject to approval by OSD and Congress), and has the burden of balancing the Services' and DoD's budget(s). The acquisition community, as used here, includes both government and industry agencies involved in developing and fielding military systems.

"…to fulfill the warfighter's materiel needs while maintaining Cost As an Independent Variable (CAIV)": indicates the use of a strategy that balances mission needs with projected

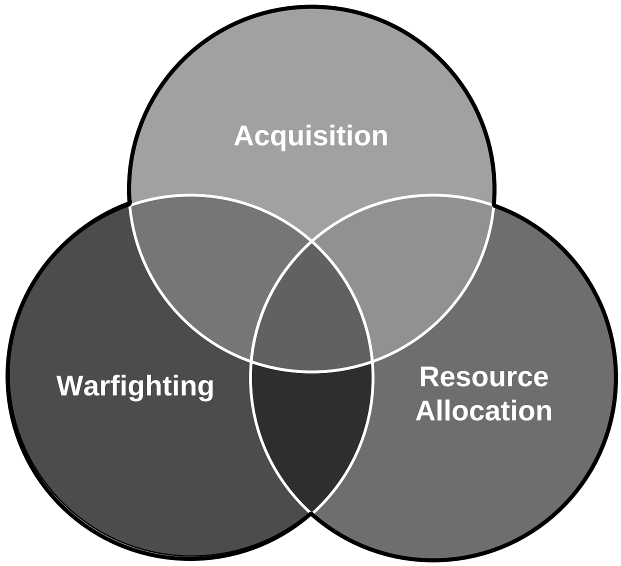


Figure 2-4. Three Principal Interacting Communities

out-year resources. We are now saying that we will trade performance in order to achieve our cost objective. By linking improved cost models with our computer-aided engineering tools, we'll be able to better predict the costs of different alternatives so as to make better informed tradeoff analyses.

"…over the system's entire life cycle" means to look both within and across all phases of the program, as early as possible during the acquisition of the system. It encompasses the collaborative use of simulation beyond the traditional performance issues to address the system's entire life cycle cost issues during the design, to include manufacturability, supportability, lethality, sustainability, mobility, survivability, flexibility, interoperability, reliability, and affordability.

"…and within the DoD's system of systems." This signifies to fully explore the system's interaction within and impact upon the DoD's system of systems, to capture the desire for effective total systems integration, as well as the collaborative use of M&S across programs. As the United States participates in greater numbers of combined operations, this aspect of the definition will have to be expanded to include a "system of systems" look across allied systems and programs as well.

Figure 2-5 graphically illustrates the three dimensions that SBA attempts to integrate. First, the vertical dimension is where M&S has been traditionally applied within each program phase, without much regard to reuse later in the program. The second dimension SBA attempts to integrate is the horizontal application of M&S across the phases of the program. More than just sticking with and

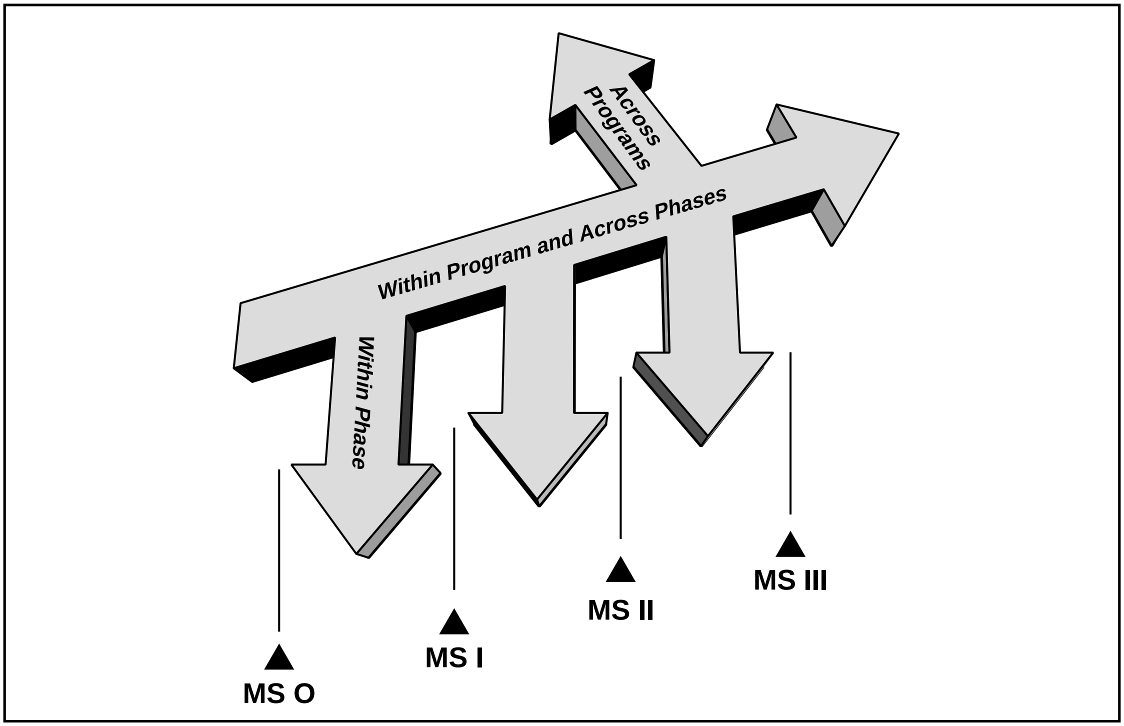


Figure 2-5. Application of M&S Across Three Dimensions

growing models over the life of a program, this means addressing the entire life cycle's issues as early as possible during the design. The acquisition community must stay focused on the real goal, which is to produce superior weapon systems, not superior virtual prototypes. The key to success is to get the design right *before* building the system, after which, in effect, the design becomes frozen. This horizontal application across phases of the program indicates an attempt to explore the cost drivers across the entire life cycle of the system, and when it makes sense, to address those issues in the design. For example, more reliable systems can translate into better combat effectiveness, as well as potential manpower decreases for maintenance, decreased mobility footprint, and reduced sparing levels. Acquiring good cost figures for these types of operations and support costs across the expected life of the system will help determine how much should be spent on reliability during system design. After production, as we continue to refine our system models with field data and operator input, the simulations will help us decide if we need to modify or build a new system, as well as consider non-materiel solutions. Looking at the furthest point in the life cycle, there may even be disposal costs that could be mitigated by changes in the design. While the importance of looking at disposal costs may seem somewhat far-fetched, it is interesting to note that the Army spends about $100 million a year demilitarizing ammunition, of which $13 million alone is for stocks from World War I.[33] If we don't start looking at disposal costs during the design, we may find that in the future, we won't be able to afford to buy the next-generation system, because we couldn't afford to dispose of the current one.

Finally, the third dimension SBA attempts to integrate is across programs. If we continue to maximize each system alone, the overall system of systems will be less than optimal. Programs need to recognize the value of the interaction of their system within the overall system of systems. Individual programs cannot afford to build everything themselves; they need to rely on each other for their similar needs. There are few design tradeoff analyses being conducted within the services between their own programs, much less between different services' programs. Currently, the Joint Requirements Oversight Council (JROC) reviews all Mission Need Statements (MNS) for joint applicability, and follows up on major programs before milestone reviews. To do these tradeoffs effectively, however, they have to be made at a level much lower than the JROC. The capability to do these tradeoff analyses will begin to extend beyond the traditional interface control procedure method, which allows each individual system to be optimized, but which results in the overall system of systems' performance being sub-optimized. Failure to look at the big picture can also result in over-designing systems as well as unnecessary duplication of effort, both of which waste resources.

When we begin to look outside a single system, we see even fewer interactions of these issues in the context between systems, as for example the maintenance and logistics considerations between the next generation amphibious assault vehicle and the ships that will transport it. We see this happening even today within large, integrated weapon systems such as submarines and aircraft, where the major sub-components (sonars, torpedoes, missiles, and munitions, etc.) are designed and developed independently and integrated later after each has been built. The design interface is controlled by an interface control document (ICD), with little to no concurrent design tradeoffs possible across the ICD.

1. DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary*, December 1997.

2. *Ibid.*

3. Defense Modeling and Simulation Office (DMSO), Verification Validation & Accreditation (VV&A) Recommended Practices Guide (November 1996), Chapter 1 Overview, pp. 1-4.

4. DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary*, December 1997.

5. DMSO, VV&A Recommended Practices Guide.

6. *Ibid.*

7. *Ibid.*

8. DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary*, December 1997.

9. Aggregation definition from DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary,* December 1997.

10. L.K. Piplani, J.G. Mercer, and R.O. Roop, *Systems Acquisition Manager's Guide for the Use of Models and Simulations,* Report of the Defense Systems Management College 1993-1994 Military Research Fellows, DSMC Press, September 1994.

11. Piplani et al, *ibid.*

12. *Ibid.*

13. *Ibid.*

14. *Ibid.*

15. DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary,* December 1997.

16. *Ibid.*

17. *Ibid.*

18. *Ibid.*

19. *Ibid.*

20. *Ibid.*

21. *Ibid.*

22. *Ibid.* The authors have removed the word "internetted" from the beginning of this definition as it is not necessary to be connected to the internet in order to have a synthetic environment.

23. *Ibid.*

24. Dan Fink; Deputy, Acquisition Logistics Integration; Deputy Chief of Naval Operations (Logistics), OPNAV N4; interview by authors 8 July 1998.

25. William S. Cohen, Secretary of Defense, *Annual Report to the President and the Congress,* 1998.

26. Fink, *ibid.*

27. General Richard E. Hawley, Commander Air Combat Command, Keynote Address at 19th Interservice & Industry Training, Simulation and Education Conference, 2 December 1997, Orlando, FL.

28. Dr. Jacques S. Gansler, Under Secretary of Defense (Acquisition & Technology), *"M&S in Defense Acquisition,"* memorandum, 16 March 1998.

29. DoD Acquisition Council of the Executive Council on Modeling and Simulation, 5 December 1997.

30. DoD Guide to Integrated Product and Process Development; Office of the Under Secretary of Defense (Acquisition and Technology), February 5, 1996.

31. Stefan Thomke, "Simulation, Learning and R&D Performance: Evidence from Automotive Development," *Research Policy* 27 (1) (May 1998), 55-74.

32. CJCSI 3170.01, Requirements Generation System (Formerly MOP 77)), 13 June 1997.

33. Kern, *ibid.*

3

BACKGROUND

There are numerous studies, papers and program examples that highlight the benefits M&S can provide in technical risk reduction, time savings, direct cost savings and/or cost avoidance, and management risk reduction. Since many of these documents are continually being refined (particularly in the dynamic growth area of M&S), it is important to view them first-hand for possible changes.[1] For example, the Army recently coined the phrase Simulation and Modeling for Acquisition, Requirements and Training, or SMART, to describe their initiative for SBA.[2]

This chapter presents current policy and guidance, previous studies and conclusions, and some assumptions and trends upon which SBA depends. Thus far, the only reference to Simulation Based Acquisition that appears in the Defense Acquisition Deskbook is Dr. Gansler's 16 March 1998 memorandum previously mentioned in Chapter Two. We expect this will soon change, however, as the acquisition community continues to implement this "smarter" way of doing business. The following synopses are a quick walk-through of recent information relevant to SBA.

Guidance

DoD 5000.1, "*Defense Acquisition*"

This directive encourages the use of M&S by stating that "models and simulations shall be used to reduce the time, resources, and risks of the acquisition process and to increase the quality of the systems being acquired. Representations of proposed systems (virtual prototypes) shall be embedded in realistic, synthetic environments to support the various phases of the acquisition process, from requirements determination and initial concept exploration to the manufacturing and testing of new systems, and related training."[3]

DoD 5000.2-R, "*Mandatory Procedures for MDAPs and MAIS Acquisition Programs*"

This directive mandates that "accredited modeling and simulation shall be applied, as appropriate, throughout the system life cycle in support of the various acquisition activities: requirements definition; program management; design and engineering; efficient test planning; result prediction; and to supplement actual test and evaluation; manufacturing; and logistics support. [Program Managers] shall integrate the use of modeling and simulation within program planning activities, plan for life cycle application, support, and reuse models and simulations, and integrate modeling and simulation across the functional disciplines."[4]

Regarding test and evaluation, it further states that "modeling and simulation shall be an integral part of test and evaluation planning…Test and evaluation programs shall be structured to integrate all developmental test and evaluation (DT&E), operational test and evaluation (OT&E), live-fire test and evaluation (LFT&E), and modeling and simulation activities conducted by different agencies as an efficient continuum. All such activities shall be part of a strategy to provide information regarding risk and risk mitigation, to provide empirical data to validate models and simulations, to permit an assessment of the attainment of technical performance specifications and system maturity, and to determine whether systems are operationally effective, suitable, and survivable for intended use."

For operational test and evaluation, it states that "The use of modeling and simulation shall be considered during test planning. Whenever possible, an operational assessment shall draw upon test results with the actual system, or subsystem, or key components thereof, or with operationally meaningful surrogates. When actual testing is not possible to support an operational assessment, such assessments may rely upon computer modeling, simulations (preferably with real operators in the loop), or an analysis of information contained in key program documents. However, as a condition for proceeding beyond LRIP, initial operational test and evaluation shall not comprise an operational assessment based exclusively on computer modeling; simulation; or, an analysis of system requirements, engineering proposals, design specifications, or any other information contained in program documents (10 USC2399). The extent of modeling and simulation usage in conjunction with operational and test evaluation shall be explained in the Test and Evaluation Master Plan…."[7]

For Live Fire Test and Evaluation on other than ACAT 1A programs, it states: "…Alternatively, in the case of a covered system (or covered product improvement program for a covered system), the USD(A&T) or the CAE [Component Acquisition Executive] may waive the application of the required survivability and lethality tests and instead allow testing of a system or program by firing munitions likely to be encountered in combat at components, subsystems, and subassemblies, together with performing design analyses, modeling and simulation, and analysis of combat data in lieu of testing the complete system configured for combat."[8]

Regarding the four key systems engineering tasks of requirements analysis, functional analysis/allocation, design synthesis and verification, and system analysis and control, it states that "The verification of the design shall include a cost-effective combination of design analysis, design modeling and simulation, and demonstration and testing.…"[9]

DoD Directive 5000.59, "*DoD Modeling and Simulation (M&S) Management*"

The purpose of this directive is threefold. First, it establishes DoD policy, assigns responsibilities, and prescribes procedures for the management of M&S. Second, it establishes the DoD Executive Council for Modeling and Simulations (EXCIMS). Third, it establishes the Defense Modeling and Simulation Office (DMSO).

It directs that it is DoD policy that “Investments shall promote the enhancements of DoD M&S technologies in support of operational needs and the acquisition process; develop common tools, methodologies, and databases; and establish standards and protocols promoting the internetting data exchange, open system architecture, and software reusability of M&S applications. Those standards shall be consistent with current national, Federal, DoD-wide and, where practicable, international standards for open systems… The DoD Components shall establish verification, validation, and accreditation (VVA) policies and procedures for M&S applications managed by the DoD Component. The ‘DoD M&S Executive Agent’ shall establish VVA procedures for that application…. M&S applications used to support the major DoD decision making organizations and processes (such as the Defense Planning and Resources Board; the Defense Acquisition Board; the Joint Requirements Oversight Council; and the DoD Planning, Programming, and Budgeting system)… shall be accredited for that use by the DoD Component for its own forces and capabilities. Each DoD Component shall be the final authority for validating and accrediting representations of its own forces and capabilities in joint and common use M&S. Each Component shall be responsive to the other Components to ensure that its forces and capabilities are appropriately represented in the development of joint and common use M&S.”[10]

DoD 5000.59-P, “*Modeling and Simulation (M&S) Master Plan*”

This plan establishes numerous M&S activities. First, it establishes the DoD vision for DoD M&S and outlines a strategy for achieving future DoD M&S-based capabilities. Second, it assigns M&S implementation responsibilities and provides guidelines for the development, cooperation, and coordination of DoD M&S efforts. Third, it establishes DoD M&S objectives, identifies action, and, where possible, assigns responsibilities for accomplishing them. Fourth, it provides a basis for developing supporting plans and programs, including the DoD Modeling and Simulation Investment Plan (MSIP), and the DoD Component’s M&S master and investment plans. Fifth, it provides justification for resource allocations to M&S within DoD Component programming and budgeting processes and fosters the integration of the defense and civilian M&S bases into a unified national and international base using common standards, processes and methods.[11]

DoD Manual 5000.59-M, “*DoD Modeling and Simulation (M&S) Glossary*”[12]

This manual prescribes a uniform glossary of M&S terminology for use throughout the Department of Defense. In addition to the main glossary of terms, it includes a list of M&S-related abbreviations, acronyms, and initials commonly used within the DoD.

DoD Instruction 5000.61, “*DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A)*”

This Instruction implements policy, assigns responsibilities, and, prescribes procedures for the VV&A of DoD M&S. It designates the Defense Modeling and Simulation Office (DMSO) as the DoD VV&A focal point, to be the central source of DoD VV&A data and information and to assist DoD and non-DoD organizations, as requested, in resolving VV&A issues or obtaining information on DoD VV&A practices. It specifies that information and data on VV&A activities will be readily available through the DoD M&S Resource Repository (MSRR) system including, as a minimum, DoD Component VV&A policies and procedures, V&V results, and accreditation documentation. This instruction also specifies minimum documentation requirements for verification and validation information, and accreditation results.[13]

"Department of Defense Verification, Validation and Accreditation (VV&A) Recommended Practices Guide"

This guide provides background and information on recommended principles, processes, and techniques for use in DoD VV&A efforts that support the analysis, acquisition, and training communities.[14]

"Simulation, Test, and Evaluation Process (STEP) Guidelines"

Provides a set of guidelines for the program manager to refer to in implementing the DoD's October 3, 1995 direction to make the Simulation, Test and Evaluation Process an integral part of Test and Evaluation Master Plans. STEP proposes a Model-Simulate-Fix-Test-Iterate approach, and is defined as "…an iterative process that integrates simulation and test for the purpose of interactively evaluating improving the design, performance, joint military worth, survivability, suitability, and effectiveness of systems to be acquired and improving how those systems are used." STEP is described as "a test and evaluation answer to the DoD challenges of implementing IPPD and SBA."[15]

Previous and On-Going Efforts

"Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process," **Science Applications International Corporation, October 1996**

The purpose of this report was to cite documented contributions to the total acquisition process. It concluded that "There is consistent evidence of M&S being used effectively in the acquisition process but not in an integrated manner across programs or functions within the acquisition process. Substantial evidence has been collected from individual success stories, though the benefits are not readily quantifiable into a general standard. The key is in focusing on the integration of M&S applications, across acquisition programs and throughout the process, not in exploring the applications themselves…."[16]

In attempting to quantify metrics, it noted "cost savings are especially difficult to quantify" and are often "more correctly classified as 'cost avoidance' and are measures of significant additional work or results that were obtained using M&S tools which would have cost the reported 'savings' if they had been obtained by more traditional methods." This study grouped the challenges that preclude the seamless use of M&S in the acquisition process into technical, cultural, and managerial challenges, as noted below:

Technical Challenges:

- Interoperability of M&S Tools;
- Availability of Data Descriptions;
- Security/Sensitivity of Data;
- Physics-based M&S;
- Hardware and Software Limitations;
- Variable Resolution.

Cultural Challenges:

- Acquisition Processes;
- Incentives for M&S Use;
- M&S Workforce;
- Acceptance of M&S.

Managerial Challenges:

- OSD and Service Guidance;
- Ownership of Data;
- VV&A Requirements;
- Funding Process;
- Use of System Models.

This report defined SBA as a "term to characterize the general *approach* of significantly increased use of M&S tools and the new *processes* which they enable in a new, more integrated approach to program development" (italics emphasis added). It further characterized SBA in terms of a systems engineering *process* by saying "The positive results of simulation efforts in systems engineering have become evident in what we refer to as Simulation Based Acquisition."

Finally, Appendix C of the October 1996 study contains a useful summary of previous studies and recommendations dating from 1989 to 1995.

Common Operating Digital Environment (CODE)

CODE, a DoD initiative related to SBA, is being co-sponsored by the Assistant Deputy Undersecretary of Defense for Logistics Reinvention and Modernization (ADUSD/LR&M), and the National Defense Industrial Association (NDIA). A joint industry- and government-working group is developing a framework for a "large-grained interoperability" technical environment to enable digital weapon system life cycle information management by 2002. The vision is for government and industry partners to create, exchange, and sustain information solely in a digital environment. The CODE will provide access to digital data across the virtual extended enterprise, and the functionality to support business processes and decision making. The initial report is cognizant of SBA and notes that the Joint Technical Architecture and its subsystem High Level Architecture need to be reviewed with other stovepipe architectures to ensure an optimum life cycle environment.[17]

Defense Systems Affordability Council (DSAC)

In December 1997, the DSAC identified three fundamental areas contributing to the affordability of acquisition programs: 1) reduction of total ownership costs; 2) 50 percent reduction of acquisition program cycle time for new systems; and 3) realistic programming and program stability (zero percent program cost growth) enabled by a broad range of potential improvements in requirements setting, funding management, and acquisition practices.[18] As noted in the previous chapter, Simulation Based Acquisition contributes to all three of these objectives.

Joint SBA Task Force

The Acquisition Council of the Executive Council on Modeling and Simulation commissioned a six month effort to develop a road map in which DoD and Industry are enabled by robust, collaborative use of simulation technology that is integrated across acquisition phases and programs. The Terms of Reference for this effort called for six major items to be included in the road map:

1. near- and long-term DoD actions needed to accelerate the SBA concept;

2. industry actions needed to accelerate SBA;

3. notional representations of systems architectures and a conceptual framework to identify key requirements for seamless data transfer and interaction;

4. opportunities for reuse and commonality across programs;

5. primary ownership of each module in the systems architecture; and

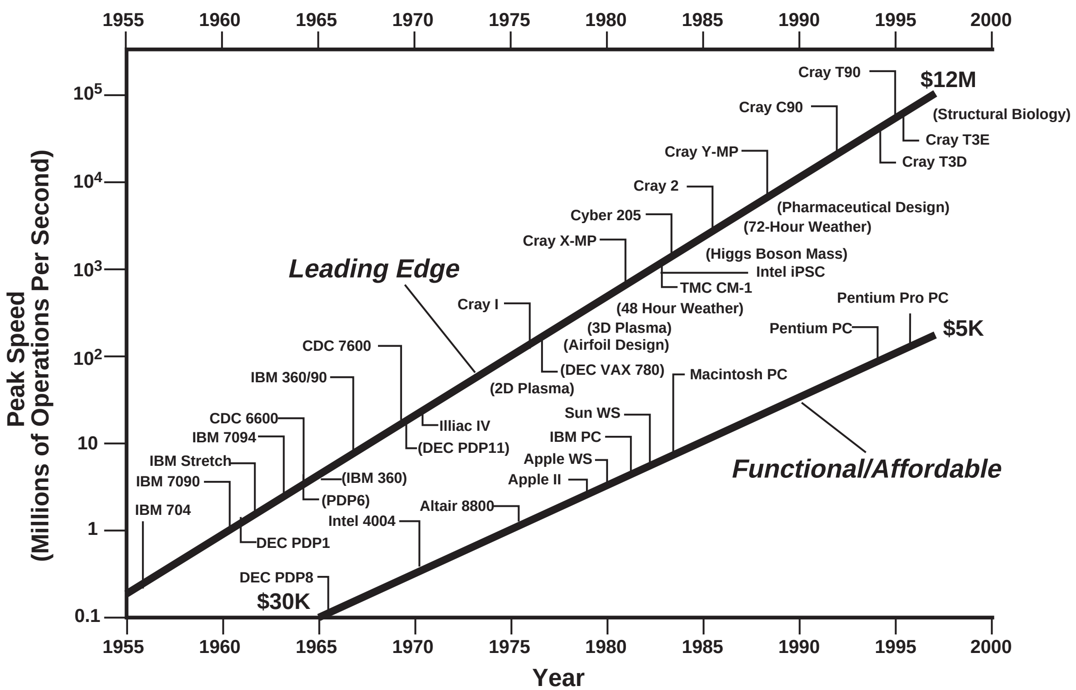
6. estimated government and industry investments needed to implement the proposed road map, and methods to determine the return on investment.[19]

The SBA Task Force is ongoing during the publication of this research effort, and their results will be presented at a conference in November 1998.

Assumptions, Trends, and SBA Enablers

Brigadier General Robert Armbruster, Deputy for Systems Acquisition at the U.S. Army Aviation and Missile Command, notes that three change factors now make SBA possible: technology, advocacy, and Life Cycle Management.[20]

Technology has advanced to the point where it is often less expensive to simulate processes, components, and systems, than it is to physically create or run them. Computing resources



Reprinted from *Research Policy*, Volume 27, Thomke, Stefan. "Simulation, Learning and R&D Performance: Evidence from Automotive Development," pp. 55-74, 1998, with permission from Elsevier Science.

Figure 3-1. Growth in Computing Power

that were worth $30K in 1960 only cost about 10 cents today.[21] In 1965, Gordon Moore (who co-founded Intel Corporation in 1968) made the observation that computing power was doubling every 18-24 months. Now known as Moore's Law, his theory has proved to be remarkably accurate: in 26 years, the number of transistors on a chip has increased more than 3200 times, from 2300 on the 4004 processor in 1971, to 7.5 million on the Pentium II processor.[22] This exponential growth in computing power is shown graphically in Figure 3-1.[23]

In 1960, many companies began using simulation tools, but they were often inadequate.[24] Recent increases in computing power and simulation tools, however, have greatly increased the capabilities of M&S efforts to a program. While physical models and prototypes do not represent reality completely, programs have grown accustomed to using them and understand their limitations. Now, programs are finding that in many instances the computer models are more correct than the physical models. The following example highlights this point. The experiment, to be run in both the physical and virtual, was to test the ability of a ship's compartment to withstand an explosion. During the validation testing of the ship's model, the test engineers could not get the computer simulation results to agree with the actual physical test results. The test design for the compartment called for a circumference weld, which had been correctly included in the finite element computer model. However, as the physical prototype had been incorrectly spot welded, the results of the physical test did not match the results from the simulation. When the error was realized, it was easier (and more cost-effective) to change the computer model to a spot weld, and re-run the simulation, at which time, the results matched.[25] Another example is from the automotive industry. A simulation analysis showed that the vehicle skin would rip below a certain thickness. Not believing the simulation, the engineers overrode the analysis of the simulation and made the vehicle skin thinner. During testing the skin ripped as the simulation had predicted. It was at this point that the engineers became believers in the results of simulations.

This leads to the second change factor of "advocacy." Leadership is essential to effective change in an organization and today change within an organization must be led and not just managed.[26] Within OSD and the Services senior leadership within the acquisition community is taking an active role towards the implementation of SBA. Advocacy for SBA, however, is not solely limited to senior leadership but can be found at all levels of the acquisition community. At the Electronic Proving Ground at Fort Huachuca, Arizona, they are finding that simulations can be better than physical tests. Security issues and civilian communication interference concerns limit what can be physically tested on some systems. Testing in the virtual environment removes such barriers. Thus some simulations can be more realistic than what can actually be tested in the physical.[27] Success stories, such as this and the examples in the preceding paragraph, are beginning to make believers out of the most hardened skeptics and are helping to promote this technology.

And the third change factor contributing to make SBA possible is the desire to be able to perform Life Cycle Management—simulation enables us to do LCM.[28] Simulation makes it possible to really get cost on the table and on equal footing with the performance requirements. This forces the requirements community to make the hard tradeoffs as part of the design process. As noted by BG Bergantz, Program Manager for the Army's Comanche helicopter program, SBA enables us to "put the intellectual before the physical."[29]

1. The DoD Acquisition Deskbook has a good synopsis of M&S guidance in Information Structure, Topics, Section 2.9.1 M&S in Acquisition: The Process, General Information, and Background (31 March 1998).

2. Kern and Purdy, "Simulation Based Acquisition: A Good Thing, But How Do We Get There?" *Army RD&A Magazine, July-August 1998,* p. 4.

3. DoD 5000.1, *Defense Acquisition,* 15 March 1996, (Section D Policy, Paragraph 2.f. Modeling and Simulation) 23 March 1998.

4. DoD 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs,* 23 March 1998 (Paragraph 3.4.4, Modeling and Simulation).

5. DoD 5000.2-R, *Mandatory Procedures for MDAPS and MAIS Acquisition Programs,* 23 March 1998 (Paragraph 3.4.1, Test and Evaluation Strategy).

6. DoD 5000.2-R, *Mandatory Procedures for MDAPS and MAIS Acquisition Programs,* 23 March 1998 (Paragraph 3.4, Test and Evaluation).

7. DoD 5000.2-R, *Mandatory Procedures for MDAPS and MAIS Acquisition Programs,* 23 March 1998 (Paragraph 3.4.5, Operational Test and Evaluation).

8. DoD 5000.2-R, *Mandatory Procedures for MDAPS and MAIS Acquisition Programs,* 23 March 1998 (Paragraph 3.4.9, Live Fire Test and Evaluation) (Not applicable to ACAT IA programs).

9. DoD 5000.2-R, *Mandatory Procedures for MDAPS and MAIS Acquisition Programs,* 23 March 1998 (Paragraph 4.3, Systems Engineering).

10. DoD Directive 5000.59, *Modeling and Simulation (M&S) Management, Section D, Policy,* 4 January 1994.

11. DoD 5000.50-P, *DoD M&S Master Plan (MSMP),* October 1995.

12. DoD 5000.59-M, *DoD Modeling and Simulation (M&S) Glossary,* December 1997.

13. DoDI 5000.61, *DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A),* 29 April 1996.

14. DMSO, *VV & A Recommended Practices Guide* (November 1996), Chapter 1 Overview.

15. Dr. Philip Coyle and Dr. Patricia Sanders, *Simulation, Test, and Evaluation Process (STEP) Guidelines,* 4 December 1997.

16. Anne Patenaude, et al., Science Applications International Corporation, *Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process,* Final Report, October 1996.

17. Common Operating Digital Environment (CODE) Top Level Policy Guidance Document, http://www.acq.osd.mil/cals/ accessed on 1 July 98.

18. Joint Simulation Based Acquisition Task Force Terms of Reference, April 1998

19. *Ibid.*

20. Brigadier General Robert E. Armbruster, Deputy for Systems Acquisition, U.S. Army Aviation and Missile Command, remarks during presentation at Army SBA Conference, Orlando, FL, 21-22 January 1998.

21. David Chang; Director, Vehicle Synthesis, Analysis & Simulation Process Center; General Motors, interview by authors, 31 March 1998.

22. **www.intel.com/intel/museum/25anniv/Hof/moore.htm** accessed on 5 May 1998.

23. Stefan Thomke, "Simulation, Learning and R&D Performance: Evidence from Automotive Development," *Research Policy 27* (1) (May 1998), 55-74.

24. Michael Carty, Gene Coffman, and Hwa-Sung Na, Ford Motor Company, interview by authors, 27 February 1998.

25. Myles Hurwitz, Naval Surface Warfare Center, Carderock Division, interview by authors, 18 February 1998.

26. Lieutenant Colonel Charles L. Beck, Jr., USAF, et al, *A Model for Leading Change: Making Acquisition Reform Work,* Report of the 1996-1997 DSMC Military Research Fellows.

27. John Haug, Directorate for Technical Mission, U.S. Army Test and Evaluation Command, interview by authors, 11 February 1998.

28. Armbruster, *ibid.*

29. Brigadier General Joseph L. Bergantz, Program Manager RAH-66 Comanche helicopter program, remarks during presentation at Army SBA Conference, Orlando, FL, 21-22 January 1998.

4

ESSENTIAL ASPECTS OF SBA

This chapter presents five essential features of a Simulation Based Acquisition process which, when implemented, will present the acquisition community with capabilities not currently imbedded in the current process. First, SBA will, through early and continuous involvement, allow the user to define, refine, and balance requirements. This is the critical first step in producing better, faster, and cheaper material solutions. Second, an SBA process supported by the synthetic environment, allows design teams to concurrently explore greater numbers of possible material solutions than is possible within the current acquisition process. Third, the iterative nature of the SBA design process will enable IPPD teams to converge systematically on optimal solutions more efficiently than is currently possible. Fourth, SBA will support changing the role of testing into that of being an integral part of the design process. Finally, SBA supports informed tradeoff analyses through a Decision Risk Analysis process. This chapter will explore each aspect separately. Though presented individually, when the five essential aspects of SBA are combined, their synergistic effect towards assisting the acquisition process is greater than the sum of the individual parts.

Balancing Requirements

Early user involvement is essential in defining, refining, and balancing requirements. The following quotations emphasize this point:

- "The best way to define a program is through M&S—plunk the user down into the virtual world, have him play with the concept, and work out the tactics, training, and procedures—take the user out of the abstract and into the virtual combat world."[1]

- "SBA and M&S enable you to play optometrist with the user—do you like it this way, or that?"[2]

- "We need more user input during development of the system. Simulation brings the warfighters and engineers together so that each has a better appreciation of the future system and its interaction in the future battlefield."[3]

- "Spiral development concentrates on soldier feedback. It involves the soldier who uses the equipment directly in the development process, brings all the parties together—from the user to the developer to industry."[4]

- “The warfighter only has a general notion of his requirements up front, and is unable to give a detailed description early on. M&S enables the user and the developer to walk up the spiral development ladder together.”[5]

The traditional acquisition process assumes the user completely understands the requirements and the impact each has on the program. To be more specific, it has been assumed that the user completely understands the overall cost associated with each requirement. According to Lieutenant General George Muellner, Air Force Principal Deputy for Acquisition, former Director of Requirements for Air Combat Command, and former Director of the Joint Advanced Strike Technology Program: “The old way of doing business was for the user to throw his requirement over the fence to the acquisition community, who would then spend five years working the margins, when 90% of the performance was already locked up. Now we’re getting where we can keep the trade space open, don’t lock up the requirements, and force the requirements people to deal early on with these issues.”[6]

Balancing requirements in the defense acquisition business means bringing into balance what the user wants with what can be affordably accomplished, or as stated by Lt. Gen. Muellner, converting the warfighter’s wants into affordable needs.[7] According to Col Cuff, U.S. Army Training and Doctrine Command (TRADOC) Systems Manager (TSM) for the Crusader field artillery program: “With simulation, the user has a better understanding of the cause and effect relationship between requirements, cost, and schedule. The TSM gets to see the operational impact of design and requirements tradeoffs. The user always wants everything, but previously did not have an appreciation for the cost and schedule impacts that requirements had on program execution.”[8] An SBA process supports the user through visual representation of the various design alternatives early in the design phase. The user can then compare alternatives and provide input to the design team on the value of competing designs with relationship to his requirements. Visualization also makes identification and resolution of many issues easier and faster. The entire IPPD team can see where the issues are and then focus on how to solve the problem.

System requirements are really a combination of many things: the user’s operational needs, logistics concerns, lessons learned, environmental issues, etc. These system requirements must then be balanced in terms of cost and force effectiveness. The user plays a key role in balancing requirements, and the applied use of M&S across the phases of a program can significantly affect the outcome of the final system.

Figure 4-1 shows the JSF program’s depiction of this balancing act between cost and capability in determining the most affordable solution. The JSF sets cost objectives to balance mission needs with projected out-year resources, taking into account anticipated process improvements in both DoD and the defense industries.[9]

Numerous Design Alternatives

Concurrent systems engineering can be viewed as a process of balancing requirements, or making compromises between competing requirements. Its primary function is to ensure the product meets the customer’s cost, schedule, and performance needs encompassing the

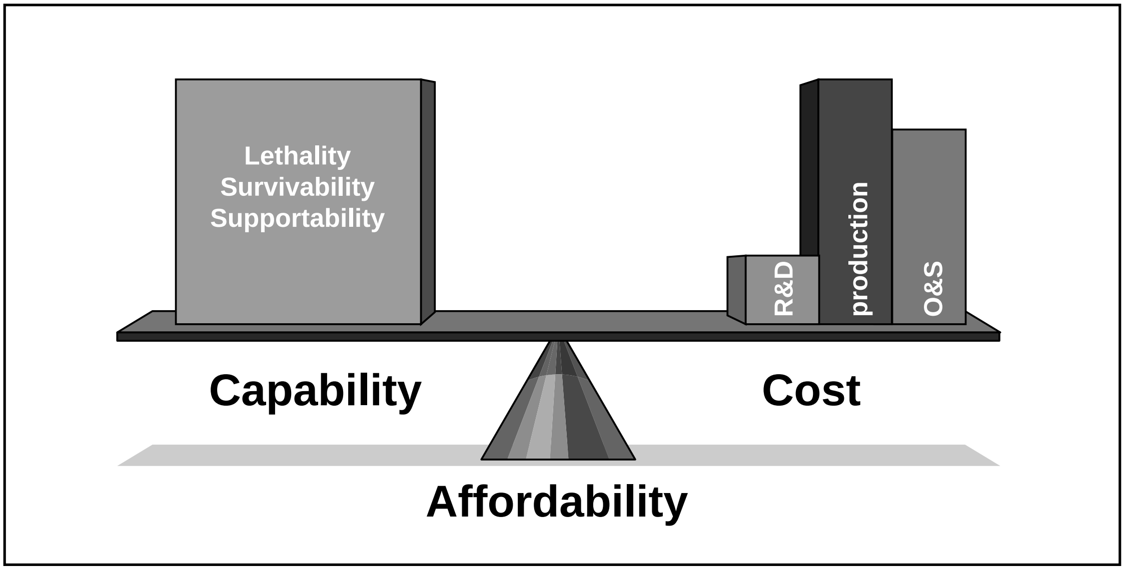


Figure 4-1. Affordability: Capability vs. Cost

total product life cycle.[10] This systems engineering approach is not new; what is new is the ability to conduct many parts of this process in the synthetic environment using M&S. The benefit of doing this process in the synthetic environment is that designers and developers can try things without fear of failure. A recent report on virtual prototyping noted that during the design cycle, a hesitancy for revisions exists once a marginally working system has been achieved, as a result of the increased risk associated with making changes.[11] This increased risk is a result of the time lost and the associated cost of building alternative hardware, even though the alternative may be a superior design.

Because making design changes in a synthetic environment can be faster and cheaper (and therefore less risky) than making changes to a physical prototype, an IPPD team is able to explore more design options. Harvard University's Stefan Thomke, in his research with the automobile industry, cites a powerful example. An automotive company found that an assumption regarding a component involved in side-impact crashes was in fact false. This assumption had never been tested because it seemed obvious that making a component in a car stronger would improve crashworthiness. Physical prototypes and crashes were reserved for high payoff issues. Engineers were not willing to use costly physical testing to test assumptions they were confident about. Because it was quick and inexpensive to check out the assumption using simulation, one engineer insisted on it. Surprisingly, the team discovered that strengthening the component actually decreased crashworthiness, by unexpectedly propagating the load to another part of the vehicle. The solution was to reduce the stiffness of the component, which went against the conventional wisdom. This discovery led to a reevaluation of other reinforced areas and has improved the crashworthiness of all cars under development. These and other design changes improved crashworthiness by 30 percent—a significant increase. Interestingly, the time and cost to build physical vehicle prototypes for the two verification experiments at the completion of the project exceeded the time and cost of the entire advanced development M&S project.[12]

Once a physical prototype exists it is difficult for people to envision a new concept that is substantially different. It is very compelling for the design team to get to a point design, and then consider possible excursions or engineering changes from that point design, rather than examining the entire design space. Designing in the synthetic environment, however, decreases the cost and time of looking at alternative designs.

Thomke notes that the advantages of substituting real physical objects with virtual experimentation can be very substantial— once set up, virtual tests can be run at very little additional cost per run.[13] In addition, he notes several other benefits of virtual experimentation. These include:

- Better depth and quality of the analyses because it is possible to slow the test events down and zoom in on minute areas.

- Information from problem-solving cycles becomes available to other development tasks earlier in the development process, therefore other tasks can proceed more quickly, and higher degrees of design concurrence are feasible.

- With faster problem-solving cycles, designers will be able to push (or "front-load") problem-discovery to earlier development phases and thus make problem-related engineering changes earlier and at a lower cost.

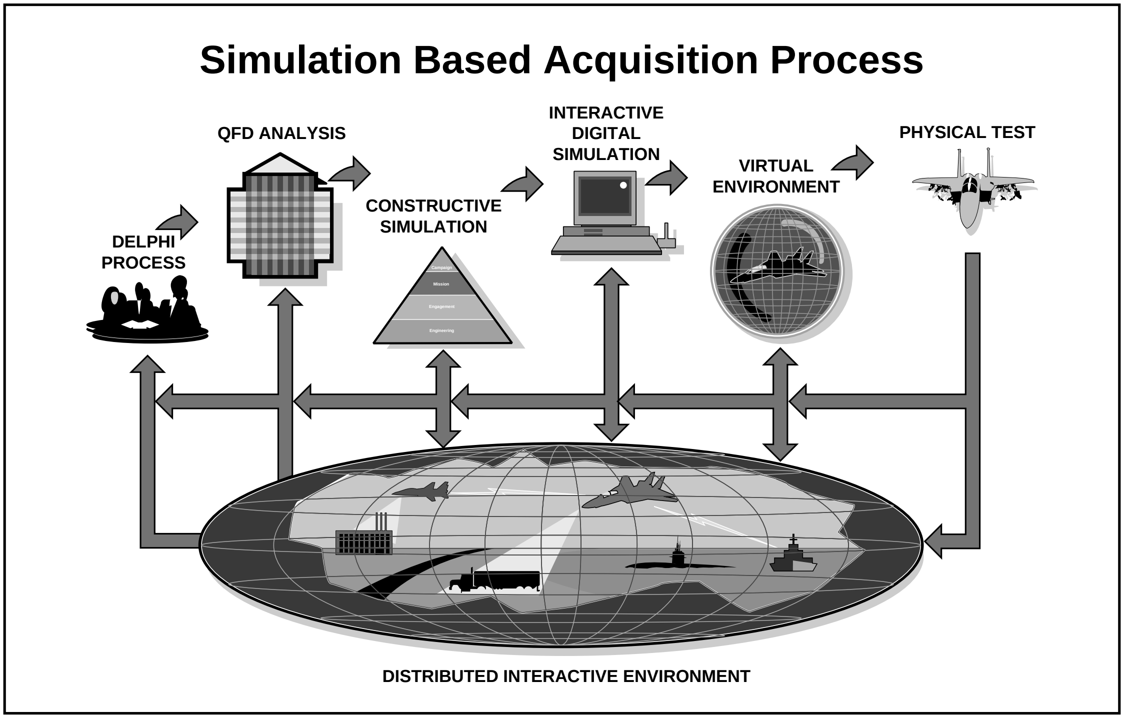


Figure 4-2. SBA Process

- Reduced cost and time to get experimental feedback encourages the design team to conduct more diverse “what if” experiments which, in turn, may lead to the discovery of more effective (and unanticipated) design changes.[14]

The Iterative Design Process

The Joint Strike Fighter (JSF) program portrays the process of iteratively designing a system using the SBA process as shown in Figure 4-2.[15] The JSF process is a building block approach, with each step building upon the previous steps as well as iterating within the steps and between steps. It begins with the Delphi Process, which is a method devised by the RAND Corporation to obtain expert judgment from multiple experts without many of the biases associated with interpersonal pressures.[16] These results are then fed into a Quality Functional Deployment (QFD) analysis, which refines the requirements into ways to accomplish those requirements. QFD provides a way of tracking and tracing tradeoff analyses through various levels, from requirements through design decisions to production and support processes, while preserving traceability to user needs.[17] These results are then used to build the appropriate level of constructive simulation. At first, these simulations will be at an aggregated campaign level, but will continue to be iterated and refined back through the previous two steps and down the constructive simulation hierarchy to mission/battle, engagement, and finally the engineering level. As more is learned, the simulation progresses to interactive digital simulation and interaction within a virtual environment, which introduces the human-in-the-loop. Again, there can be much iteration within each step, as well as feedback to earlier steps to capture the knowledge gained. As the program matures into flight test, these results are also fed back into the program to capture the knowledge, and to help challenge and possibly revise the inputs to the process.

Once a program reaches the constructive simulation step, it has the option to begin interacting with other systems in a distributed interactive environment. This can be a powerful tool for the IPPD team because it enables them to receive feedback on their system well before the design is locked in. Virtual systems can participate in exercises and experiments to determine their effect on the battlefield, and those results and warfighter feedback are captured early enough in the program to help the design team conduct more informed tradeoff analyses. In effect, the warfighter becomes an integral part of the design team.

Converging on an Optimal Design

Another view of this systems engineering and simulation process was developed by United Defense Limited Partnership and is being used on the Crusader field artillery system. Their Simulate, Emulate, Stimulate process is shown in Figure 4-3 as a top-down view, and in Figure 4-4 from a side view.[18]

The Simulate, Emulate, Stimulate process starts with a low fidelity model, and moves through the four steps of analyze, design, evaluate, and revise, successively converging until reaching a high fidelity model of the final system. Early models of the system are used in a series of simulations to evaluate concepts of potentially high-risk areas to identify and resolve deficiencies. As the system design matures, some subsystem simulations are replaced with emulations, which are models that accept the same inputs and produce the

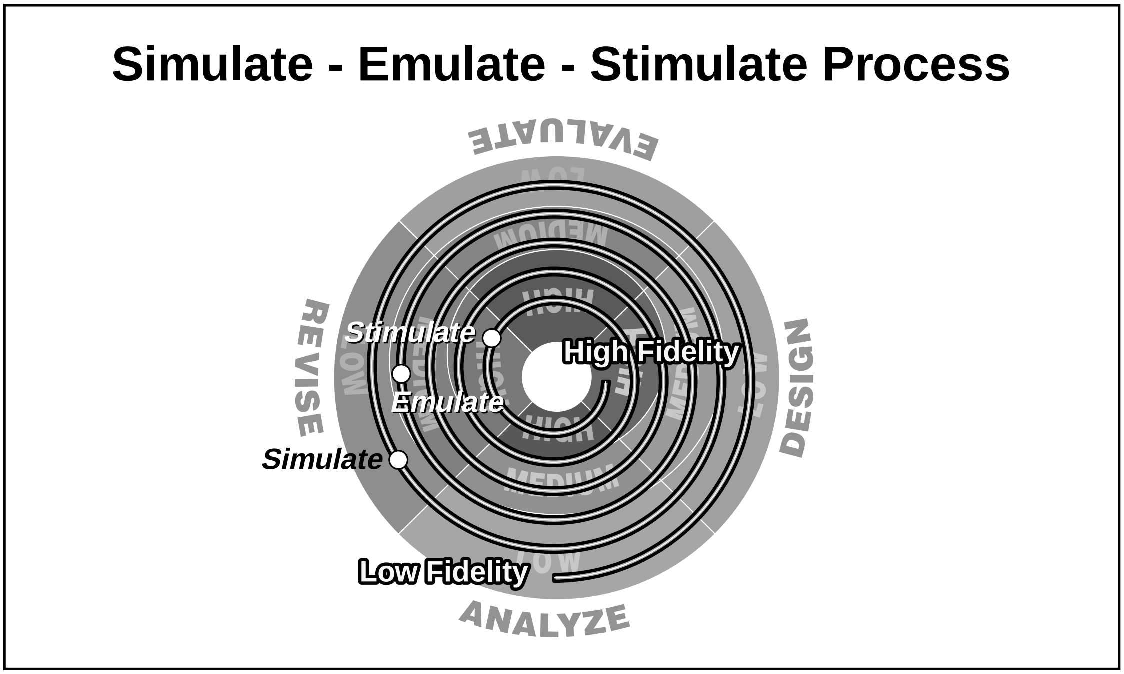


Figure 4-3. Stimulate-Emulate-Stimulate Process, Top-Down View

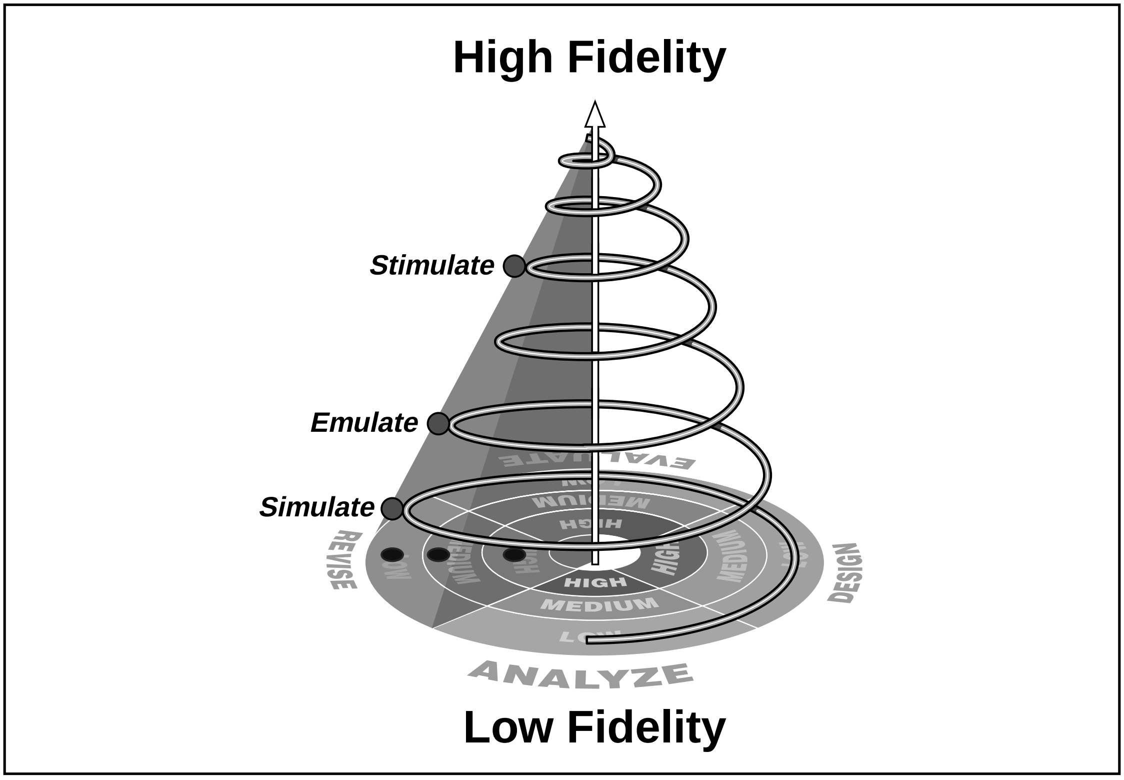


Figure 4-4. Stimulate-Emulate-Stimulate Process, Side View

same outputs as a given system.[19] These emulations have a higher level of fidelity and translate to a more detailed evaluation of the system performance. Further design maturation allows the model to stimulate actual system hardware, leading to the final stage of bench top integration and then system test.[20]

SBA is about using simulation to explore the design space, to validate designs, and to verify that the proposed design will meet the end-user's expectations and is manufacturable, supportable, and affordable. Simulation enables the team to see the results of their design decisions not only in terms of performance, but also to project the cost of those decisions across the system's life cycle. The rapid feedback from the design iterations helps the team converge on an optimal solution—otherwise they'll continue to work on the problem until they run out of time. It's impossible to know if a single design is the best possible solution; however it is possible to evaluate one design against another. The confidence in reaching an optimal design should increase as the number of designs explored increases, particularly if there is significant feedback and learning taking place between the design iterations.

Data and personnel interfaces need to be seamless and integrated to facilitate rapid design iterations. This requires an integrated data environment to work effectively. A Product Information Management (PIM) tool is extremely important to manage across the virtual enterprise and can facilitate widely separated teams. It controls and provides easy access to the large quantities of engineering and product-related data that are generated during concurrent engineering, while tracking the numerous rapid changes from different sources in the organization that often occur at the same time.[21] Concurrent engineering demands a great deal of work-in-process information. The PIM links the engineering tools with the other tools necessary to manage a fully integrated environment, such as office automation, systems engineering, business management, configuration management, reference library, and particularly web and Internet connectivity for cost-effective subcontractor access.

The integrated data environment is changing the entire design process. For example, on the Crusader program, critical information no longer exists in specifications and drawings. It's now in very large databases that need to be managed and linked. Requirements for the Crusader now exist as a highly structured, hierarchical, linked data set of over 7,000 requirements. Using their integrated data environment management system, the Crusader design team can quickly identify the collateral impact of a requirements change.[22] The team can trace the top-level warfighting tasks all the way down to the detailed design and back up to the final product. During design iterations, if the final product falls short of expectations in some areas (for example in initial acquisition cost, interoperability, or maintainability), this traceability from requirements to design will be key to enabling the program office, in conjunction with the warfighter, to make smart tradeoffs.

Test as an Integral Part of Design

The traditional "build – test – fix" or "test – fix – test" process is giving way to a new process in which test is becoming an integral part of design. As mentioned before in Chapter Three, the Simulation, Test, and Evaluation Process (STEP) Guidelines calls it a "model – simulate – fix – test – iterate" approach, wherein there are many iterative loops possible in this process.[24]

Dr. Henry Dubin, Technical Director of the Army's Operational Test and Evaluation Command (OPTEC), emphasizes this changing process by saying that we no longer "conduct test and evaluation for the purpose of determining pass or fail of critical threshold parameters…[we now] focus testing on what the acquisition team needs to learn—test to learn, and evaluate to understand the [operational] impact of what we have learned on mission accomplishment."[25]

When viewing the test process, it's important to keep in mind that both physical tests and virtual tests have limitations. Dr. John Foulkes, Director of the Army's Test and Evaluation Management Agency, notes that the "test and evaluation community should view anything short of actual war as being simulation, including live testing. Program Managers should ensure the right mix of constructive (digital) simulation, virtual simulation, and live simulation (testing), and continually re-evaluate why and how we test. Constructive and virtual simulation should reduce the burden on the amount of live simulation required, thereby reducing the time and cost of testing."[26]

Models, by definition, do not represent reality completely.[27] This applies to both physical and synthetic models. Models are, therefore, an attempt at replicating reality. Many reasons may prevent a model from accurately representing reality or being a high fidelity model. Inaccuracy of the model can be the result of the inability to capture all the attributes of the real situation, possibly because of human error, ignorance, time limits, or economics.[28] Many times we use M&S to overcome physical limitations of live testing, including safety concerns, interoperability issues, interference with civilian activities, non-availability of the threat, and affordability.[29] In part M&S is done to reduce the cost of representing aspects of the real that are irrelevant to the experiment, as well as to control out some aspects of the real to simplify the analysis of the results.[30]

Dr. Dubin proposes a test strategy of using M&S to design and develop the system, to mature the models with the system, and to use the test data for calibrating and maturing the system model. By truly integrating testing early on we should gain synergies to greatly enhance the overall value of the program. He emphasized his point by stating the converse: "Building a simulation solely for the purpose of reducing your Milestone III testing requirements is almost always a waste of money."[31] Dr. Phil Coyle, Director of Operational Test and Evaluation, Office of the Secretary of Defense, noted the same importance of early test involvement: "M&S and testing are intertwined; when they are not, neither is effective."[32]

The benefits of M&S to the test and evaluation community are numerous, among them the ability to:

- conduct full and continuous evaluation of the system;
- evaluate system performance where live simulation is neither feasible or practical;
- identify and concentrate the live simulation resources in the high risk areas;
- stress the system at less than system level;
- conduct excursions for the development of test and evaluation plans and to identify live simulation scenarios.[33]

Involving the tester early in a program may also allow the tester to influence the design to minimize what must be tested and to facilitate the testing that must be conducted. The knowledge gained through M&S of a system will enable the test community to design and conduct more effective and efficient testing.

The Crusader program noted that the biggest challenge is to combine testing and M&S to leverage savings in time and resources, while satisfying the decisionmakers that the requirements are met.[34] The test community needs to be on board early as part of the design solution. This way they gain credibility in the models as they're being used early in the program, and build in confidence in the models through incremental testing.

The intent of modeling and testing is also beginning to change. For example, the role of the Navy's David Taylor Model Basin has become more of validating models rather than designing models. The purpose of testing is evolving into validating the model so that the analytical calculations derived from the model are believable.

A mix of analytical and physical testing is often the right answer, depending upon the credibility and confidence in the tools. New program starts may require physical prototypes to prove out the models, since there may not be known models from which to build. But the goal remains the same—to conduct a combination of M&S and testing in order to get a better product. As one tester stated: "The old paradigm was to test a company of tanks. The new paradigm will be to test a platoon, but to simulate a battalion."[35]

Decision Risk Analysis

Though modeling and simulation costs are coming down, they still can be very expensive to apply. Programs probably cannot afford to use M&S on every issue and need the ability to prioritize their efforts. One way to prioritize efforts is through a methodology called Decision Risk Analysis (DRA), which quantifies and ties together cost, schedule, performance, producibility, risk, and quality to permit informed tradeoff analyses.[36] A decision risk analysis tool quantitatively provides the program manager with a means of assessing a program's probability of achieving program success, while employing a CAIV strategy. If the assessed risk is low and well known, combinations of many program activities may be acceptable. If assessed risk is substantial and/or unknown, a detailed break out of activities accompanied with detailed time, cost, and performance estimates for completion of those activities from assessment in a Delphi-type environment may be required.

One such tool is the Venture Evaluation and Review Technique (VERT), which is a government-tool designed to do DRA.[37] It is a Monte Carlo simulation-based tool that aids program managers in measuring risk in an unbiased manner. VERT uses the same approach as a Gannt chart and it adds probability to make it a risk measurement tool. To build a more accurate Gannt chart you interview IPT members to get a more accurate assessment of how long activities will take. You end up with a range of time an event could take, along with a corresponding probability. You can then run a series of "what ifs" to determine various outcomes as parameters are changed. The Gannt chart will allow you to identify the program's critical path for cost, schedule, and performance. You can then focus simulation in those high-risk areas to reduce programmatic risk. If the risk is low, no modeling may be required, or a low fidelity, kinematics-based CAD/CAM model may be all that is required for proof of principle. On the other hand if the risk is high, a higher fidelity simulation or physical test may be required for proof of concept. Implementing a program like VERT can take a lot of manpower to collect and maintain the data; however, it can pay big dividends by helping determine the high risk areas. A DRA approach helps the manager determine where to employ modeling and simulation efforts and to what level of fidelity.

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3. Rob Beadling, John J. McMullen Associates, Inc., interview by authors, 6 March 1998.

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6. LTG George Muellner, USAF, Air Force Principal Deputy for Acquisition, interview by authors, 30 March 1998.

7. Colonel Kenneth Konwin, USAF, Director of Defense Modeling and Simulation Office, interview by authors, 31 July 1998.

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9. Major General Leslie J. Kenne, Program Manager, Joint Strike Fighter Program, "Joint Strike Fighter—The Affordable Solution" 30 April 1998 briefing, on-line reference **www.jast.mil/html/progbriefs.htm** on 22 April 1998

10. Defense Acquisition Deskbook, Information Structure 2.6.1 Systems Engineering, Frontline Wisdom and Advise, AFMC - The Engineering Process From Industry Point of View, Submitted by Mr. Kammer, HQ AFMC/ENPP (09 June 1998).

11. Tim Thornton, Coleman Research Company (CRC), Collaborative Virtual Prototyping System (CVPS), 9 January 1997.

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13. *Ibid.*

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15. Colonel Phil Faye, USAF, Joint Strike Fighter Program briefing, 30 March 1998.

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20. Bruce Van Wyk, United Defense Limited Partnership, Crusader Program briefing, 2 April 1998.

21. John Krouse, "Manager's Guide to Computer Aided Engineering," pp. 156-157.

22. Bruce Van Wyk, United Defense Limited Partnership, Crusader Program briefing, 2 April 1998.

23. Dr. John B. Foulkes; Director, U.S. Army Test and Evaluation Management Agency; Presentation and remarks at Army SBA Conference, 21-22 January 1998.

24. Dr. Philip E. Coyle and Dr. Patricia Sanders, *Simulation, Test, and Evaluation Process: STEP Guidelines*, 4 December 1997, pp. 1-3.

25. Dr. Hank Dubin; Technical Director, U.S. Army Operational Test and Evaluation Command; Presentation and remarks at Army SBA Conference, 21-22 January 1998.

26. Foulkes, *ibid.*

27. Thomke, *ibid.*

28. *Ibid.*

29. Dubin, *ibid.*

30. Thomke, *ibid.*

31. Dubin, *ibid.*

32. Dr. Philip E. Coyle; Director, Operational Test & Evaluation, Office of the Secretary of Defense; Presentation to 1997 Defense Modeling and Simulation Office Industry Days, 22 May 1997.

33. Foulkes, *ibid.*

34. Colonel William Sheaves, U.S. Army; Project Manager, Crusader field artillery program; Presentation and remarks at Army SBA Conference (21-22 January 1998).

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5

EXPANDING THE SBA ENVELOPE

In this chapter we describe how Simulation Based Acquisition practices within the Department of Defense may be expanded. To set the stage, we present the factors influencing the extent to which a program can implement SBA. Next, we present the areas that programs can "push" while implementating SBA activities within their program. Finally, we discuss the "pull" programs will receive from the warfighting and programming communities once they and other programs begin implementing SBA .

Factors Influencing the Use of SBA – Domain, Infrastructure, and Need

Many programs are doing smart things with M&S, and many of these programs say they are already implementing SBA. Others counter that those programs are only beginning to scratch the surface of what is possible using a simulation-based approach to acquisition. They are just gaining benefits from having a common description of the product, so they cannot claim to be implementing SBA. SBA is a new approach that has a sliding scale—programs can do a little, or they can do a lot. As someone said at a recent conference, SBA is a journey, not a destination. How much SBA can be done in a program largely depends on three factors:

1. the domain the program is in;
2. how well developed the infrastructure is; and
3. how compelling a need there is to change the current way of doing business.

Regarding the first factor, how much SBA can be done will partly depend on the maturity of the program's domain. The DoD M&S Glossary defines a domain as "The physical or abstract space in which entities and processes operate. A domain can be land, sea, air, space, undersea, a combination of any of the above, or an abstract domain, such as an n-dimensional mathematics space, or economic or psychological domains."[1] If the domain is fairly mature with well-developed models, then a program has a much better chance of leveraging others' investments to their benefit. On the other hand, a program's knowledgeable industry partners may still be using blueprints and fax machines. These programs will probably have to set their sights a little lower in how far they will be able to reap the benefits of moving to an acquisition strategy based upon the heavy use of M&S.

The automotive and aerospace industries are two of the most advanced domains because of their lengthy involvement with M&S, and have had good success in developing their enterprises by integrating with their suppliers. (An enterprise is defined as "an arbitrarily-defined functional and administrative entity that exists to perform a specific, integrated set of missions and achieve associated goals and objectives, encompassing all of the primary functions necessary to perform those missions."[2]) Conversely, the U.S. shipbuilding industry has many domestic suppliers that do not have any expertise in the synthetic environment, and are unable, therefore, to provide CAD drawings (much less digital models) of their products. This impedes the benefits the prime contractors in the shipbuilding industry can accrue by using M&S, since they have the additional expense of reverse engineering the models of their suppliers' products, with all of the attendant worries about the validity of the models.

It's important to note that in spite of this limitation, the shipbuilding industry has gained significant benefits from using M&S. For example, General Dynamics Electric Boat Corporation was able to reduce the number of pipe hangars on the New Attack Submarine (NSSN) from 40,000 to about 18,000. Since hangars are a major cost item on a submarine, this equates to a major cost savings for the program. General Dynamics more than recouped their implementation costs because the cost reduction on the first boat alone exceeded the entire cost of modeling it, and they are building three more.[3]

The second factor influencing the transition to SBA will be how much of the infrastructure is in place to facilitate a program's entry into a simulation-based acquisition process. The Defense Modeling and Simulation Office (DMSO) is building many parts of this infrastructure. For example, DMSO has created the Modeling and Simulation Resource Repository (MSRR), which is a collection of models, simulations, object models, Conceptual Models of the Mission Space (CMMS), algorithms, instance databases, data sets, data standardization and administration products, documents, tools, and utilities. The MSRR is a collection of resources hosted on a distributed system of resource servers. These servers are interconnected through the worldwide web using the internet for the unclassified MSRR and through the Secret Internet Protocol Routing Network (SIPRNET) for the classified MSRR. The MSRR provides a layer of services that includes the registration of resources and users, description and quality information of resources, and specialized search capabilities.[4] DMSO has also created the Modeling and Simulation Operational Support Activity (MSOSA), which assists DoD activities in meeting their M&S needs by providing operational advice and facilitating access to M&S information and assets. The MSOSA is a contractor-staffed activity operating under the direction of the DMSO Director of Operations.[5] Programs needing M&S help or assistance should contact the MSOSA. Contact information is available through the DMSO website (mentioned previously in the preface).

DMSO is also leading a DoD-wide effort to establish a common technical framework to facilitate the interoperability of all types of models and simulations, among themselves and with command, control, communications, computers and intelligence (C4I) systems, as well as to facilitate the reuse of

M&S components. This Common Technical Framework (CTF) consists of three pieces: the CMMS, Data Standards (DS), and the High Level Architecture (HLA).[6]

The mission of the CMMS is to develop a conceptual model of the mission space for each DoD mission area to provide a common basis for development of consistent and authoritative M&S representations. Its purpose is to provide designers with an evolvable and accessible framework of tools and resources for conceptual analysis. The mission space structure, tools, and resources will provide both an overarching framework and access to the necessary data and detail to permit development of consistent, interoperable, and authoritative representations of the environment, systems, and human behavior in DoD simulation. Using this framework, designers will be able to develop a clear picture of what they wish to represent in order to produce a workable model or simulation for any application. This picture will be multi-dimensional and must include a depiction of the entities, actions, and interactions that must be represented. There will be several CMMS corresponding to broad mission areas (such as conventional combat operations, other military operations, training, acquisition, and analysis).[7]

The second piece of the CTF is the M&S Data Standards Program. The mission of the M&S DS Program is to enable data suppliers to provide the M&S community with cost-effective, timely, and certified data to promote reuse and sharing of data; interoperability of models and simulations within themselves and with the warfighter's C4I systems; and improved credibility of M&S results. The strategic objective is to establish, promulgate, and oversee policies, procedures and methodologies for M&S data requirements; data standards; data verification, validation, and certification; authoritative data sources (ADS) and data security to provide quality data as common representations of the natural environment, systems, and human behavior. The Data Program is organized into four areas: Data Engineering (including Data Interface Format (DIF) and tool development), Authoritative Data Sources, Data Quality, and Data Security.[8]

Within the Data Engineering area, the Synthetic Environment Data Representation and Interchange Specification (SEDRIS) effort is significant for facilitating SBA. Currently, there is no uniform and effective standard mechanism for interchanging synthetic environments between M&S applications. SEDRIS will support the unambiguous interchange of data between database generation systems by using a standard application programmer's interface that will allow the data to be captured from the producer's native format with accompanying explanatory metadata. Although SEDRIS by itself will not solve all interoperability problems, it will provide the technology to enable solutions.[9]

The third piece of the CTF is the High Level Architecture (HLA) program. The HLA is a com-posable approach to constructing simulations that recognizes that no single, monolithic simulation can satisfy the needs of all users; all uses of simulations and useful ways of combining them cannot be anticipated in advance; and future technological capabilities and a variety of operating configurations must be accommodated.[10] The HLA provides a common framework within which specific system architectures, or federations, are defined by three components. These are:

1. Ten rules that define the relationships among the federation components;

2. An object model template that specifies the form in which simulation elements are described;

3. An interface specification that describes the way simulations interact during operation.[11]

A federate is a member of a HLA federation, which may include federation managers; data collectors; real world (“live”) systems such as instrumented ranges, sensors, or C4I systems; simulations; passive viewers; and other utilities.[12]

The MSRR, MSOSA, and CTF are all pieces of the SBA infrastructure that facilitate the entry of programs into SBA. (We’ll have more to say about standards and interoperability in Chapter 7, Challenges to Implementing SBA.) At this stage, many of the tools needed to do enterprise-wide simulation are at an immature, “micro” level, and are not ready to handle “macro” jobs.

The big three auto makers have been solving their enterprise data interoperability needs by dictating that their first-tier suppliers must use their computer-aided design packages for development and submission of their products. (Chrysler uses Dassault Systemes’ CATIA, Ford uses SDRC’s Ideas, and General Motors uses Unigraphics Solutions, Inc.’s package). The commercial side of The Boeing Company has also standardized with CATIA. Others are choosing to solve their enterprise needs by using standards for the universal exchange of product information. For example, the Standard for the Exchange of Product Data (STEP) is an emerging international standard for representing data about products that provides a set of standard definitions for the data throughout the product life cycle.[13] Using STEP, The Boeing Company (military side) is able to successfully exchange design information between its St. Louis facility (which uses Unigraphics to design the Joint Strike Fighter’s fore body) with its Seattle facility (which uses CATIA in its role as systems integrator).[14] General Dynamics Land Systems (GDLS) uses both Pro-E and Computervision for their design software, while their vendors mostly use Autocad, Unigraphics, and Pro-E. GDLS maintains interoperablity by focusing their efforts on ensuring the accuracy of the data.[15] Likewise, United Defense Limited Partnership is using various commercially available tools (e.g. Pro-E for solid modeling and Corypheous for visualization) and linking them together to get the job done.[16] The effort a program must devote to ensuring seamless interoperability between the products of M&S tools will depend on factors such as the number of different M&S tools used, their degree of compatibility and the level which they interface. Translation efforts in the examples cited above, range from being a nuisance to being major problems that require full time support.

Regardless of the method used, programs need a way to communicate freely in their integrated data environments. HLA compliance for simulations has been mandated by OSD for 30 September 2000 and non-compliant development and modification of simulations must cease by 30 September 1998; however, “HLA is not an interoperability ‘magic wand.’ That is, HLA will not automatically make every simulation suitable for federating with every other simulation, nor guarantee a valid, meaningful exchange of information across the federation … but the HLA does provide the critical technical foundation for the interoperability of simulations among themselves, and with live systems."[17] Said another way, HLA will provide the common "plug" within a federation, but not guarantee that models from different federations will "play" together in simulation. When examining the possibilities, the real answer may often be that applications need to be "compatible but not necessarily common."[18]

A final factor influencing the transition to SBA will be how compelling a need there is to change the current way of doing business. Crisis is often the reason for change and has been a force driving many programs to turn to increasing and more innovative uses of M&S. Certainly this is the case for the Army's Comanche helicopter program. The program office used M&S extensively to conduct a competitive fly off in which two competing teams used man-in-the-loop simulation instead of building costly prototype aircraft. In addition, M&S activities allowed program management to work within budget constraints and maintain a viable program throughout developmental test and evaluation, with only one flying prototype.[19] In the automotive industry this was most apparent with Chrysler, which was on the verge of bankruptcy in the early 90s with many employees working half days. In response to this crisis, Chrysler built a new technology and design center and made a significant switch-over to using computer-aided engineering. A workforce that saw and supported the need for change made this possible. Similarly, within the DoD there is a compelling need to find a better and more affordable way of acquiring systems. It is unwise to continue business as usual in light of the rapidly evolving M&S technology that will support SBA as a better alternative.

SBA Push and SBA Pull

The domain of the program, the maturity of the infrastructure, and the degree of need will all influence how much SBA can be implemented in a program. But the key point is that any program can start moving down the path to implementing SBA. This "SBA Push" is what programs are doing within their enterprise to implement SBA, given the existing state of the domain, infrastructure, and need.

Likewise, the "SBA Pull" is the expectation and demand for SBA from outside agencies (for example, the warfighting and resource allocation communities). Dollar for dollar, programs that are implementing SBA will be perceived as better programs, because of the increased visibility, superior insight, and subsequent "better, faster, and cheaper" products.

SBA Push

We'll start first by looking at how programs can expand the envelope by moving down the path to implementing SBA. Regardless of where a program is in its life cycle, it can benefit by initiating SBA practices. It is usually not cost-effective for a program to wait until everything is completely available and in place before starting to use SBA. It's more important to get started, achieve some successes, learn, and continue to build. A good analogy is that of building a housing subdivision. Once the overall plan is in place, there's a tradeoff between the cost-efficiencies of scale and volume and the investment required. Usually this means building a few houses, selling them to generate cash flow to finance additional houses and infrastructure, and continuing to expand throughout the subdivision. An added benefit to this approach is the learning that occurs as each house is built. The last house should be significantly better, take less time, and cost less to build than the first.

Defense acquisition programs are normally inventing or reinventing a new product and inventions do not have reliability—reliability is achieved through history, use, and time. It's important, therefore, to get started in SBA in order to continually and incrementally improve the processes, rather than waiting until everything is in place. The movement towards SBA will be a progression. It has been stated that "the concept is revolutionary, but the implementation will be evolutionary."[20]

An important consideration for the program manager is to not oversell SBA. As noted by one industry manager, the rate of change towards SBA is a concern. The community must accurately portray the direction, the speed of advance, and the capabilities of the final end state of SBA so that expectations are in line with reality. There will be incremental changes and payoffs. Creating unrealistic expectations can negate any potential benefits. In particular, there may be many things that cannot be modeled well enough to get the information needed.

Does it require an up-front investment for programs to adopt SBA? Certainly there are initial investments required in terms of the computer and software purchases, as well as workforce training.[21] There are other costs, including application software changes requiring the updating and revalidation of simulations.

Much has been said about The Boeing Company's failure to recoup its approximately \$1.5B to \$2B investment for the full CAD/CAM system used on the 777 airplane. However, their automated, simulation-based design and build process enabled them to deliver a completely reliable, operational aircraft on day one, a first-of-its-kind in the commercial aircraft industry. In the past it usually took a year after delivery to work out all the software bugs, maintenance issues, and parts distribution for a new aircraft. Boeing's instant success with the first aircraft has stimulated more sales and has further benefits that extend across improved operations for the entire Boeing commercial aircraft workforce and procedures. The company continues to remain well positioned to outstrip their competition with faster aircraft upgrades.[22] With better customer satisfaction, lower operating costs, and lower maintenance costs, Boeing expects to sell more 777 aircraft. They are also able to use this technology on other aircraft for no development costs. Finally, if Boeing hadn't got the aircraft to market as quickly, Airbus might have taken some of the sales. Benefits like these are difficult to factor into the investment decision with hard data because there is no way to predict the outcome had traditional processes been used. This "cost avoidance" or opportunity cost issue makes it difficult to determine the return on investment for switching to the SBA approach. Programs can show cost avoidance figures resulting from the building of fewer prototypes, or more efficient tests, or the need for only one flying testbed. But it is very difficult, if not impossible, to put dollar values on risk reduction or a greatly improved product.

In any event, most programs probably will not receive extra funding to change over to this new SBA approach. Reality is a matter of reallocation of the existing budget to obtain the best value, and determining when that value will be received. Again, this will require a tradeoff analysis to balance specific needs with the available resources. The

Army dictates the use of a Simulation Support Plan (SSP) to effectively manage and integrate the use of M&S within acquisition programs.[23] The Air Force handles this tradeoff analysis by requiring programs to reflect their M&S strategy and requirements in the appropriate acquisition documentation, such as Operational Requirements Documents, Test and Evaluation Master Plans, and Single Acquisition Management Plans.[24] The objective of these requirements is the same: to determine the high-leverage areas that simulation can enhance, while at the same time planning to build from these successes.

High-leverage areas can vary greatly from one program to another. Factors that can influence a program's high-leverage areas are such things as the program's developmental time line and the program's strategies and goals. For example, rather than baselining a system first and then creating a trainer, programs are creating early-on test-beds that provide the opportunity to iterate and immerse the user, which can ultimately grow into a trainer.[25] Through the use of the virtual environment the Crusader program, with a simulation budget of $9M, was able to reduce the program's requirement for physical prototypes by six. At a price tag of $50M each, the program realized a total cost avoidance of $300M.[26] Strategies and goals also help identify programmatic high-leverage areas. Chrysler has reduced their cost of doing business by $800M by taking eight months out of the cycle time through the use of the virtual environment during design development. Their prototypes are now as good as the first production cars were when they were using the traditional production method.[27] General Motors does 80 percent of its manufacturing in-house (compared with Chrysler's 20 percent and Ford's 50 percent). GM's costs, therefore, are associated with tooling, and they must concentrating on increasing their confidence level before committing to tooling.[28] This goal of increasing the confidence level in the design is supported through the use of SBA practices. Ford, on the other hand, concentrates on a global, distributed engineering capability, which emphasizes the importance of product information management.[29] Designing in the virtual environment supports this strategy of distributed engineering and information management.

Many of today's programs focus primarily on the design development portion and not the full life cycle of a system and indeed, this is an important first step in achieving the full benefits of SBA. Within systems, we're just beginning to simulate beyond the traditional performance issues to address the entire life cycle's cost issues during the design. These include manufacturability, supportability, lethality, sustainability, mobility, survivability, flexibility, interoperability, reliability, and affordability. One of the nearest term capabilities that will benefit many programs is "virtual manufacturing"—the ability to look at the manufacturing issues during design.

The F-22 program is looking at supportability issues by using a 3-D model that has enabled two mechanics to influence the design by making critical inputs long before any hands-on prototypes were available.[30] The JSF program is developing the Joint Interim Mission Model (JIMM) to merge two legacy models, enabling test and training inputs to their early modeling efforts until JMASS is available.[31] The Crusader program, together with the combat development community, has jointly conducted a series of simulated warfighting experiments called Concept Evaluation Programs (CEPs), which provided early warfighter insights into the changing tactics, techniques, and procedures associated with the new weapon system.[32] During the redesign of the Boeing 737 aircraft, Boeing found that digitizing older systems where the design was only on blueprints can still pay big dividends. They did a full Digital Product Assembly and Digital Product Definition for only those parts that were new (the wing, empennage, and main landing gear). Although the digitization of the old parts was tedious, Boeing found it to be worthwhile.[33] The JSF created cost curves for each alternative during its Analysis of Alternatives, which allowed operational tradeoffs using CAIV.[34]

Using the CAIV concept, it is critical for a program manager to know how design decisions will impact on overall program costs. Some programs have developed cost models based on historical costs of similar type systems. A good example is the CVN-77 aircraft carrier program that looked at previous ships to determine what the cost drivers were throughout the life cycle of a ship.[35] This identified where the CVN-77 program should target attention to achieve the most cost reduction.

The Crusader program has pretty high confidence in its cost models and has established an Ownership Cost Working Group consisting of representatives from the contractor, user community, and the program office to identify life cycle cost drivers and methods to eliminate or minimize them. During the early phase of the Crusader's development, an independent study group was commissioned to analyze the program's requirements and design in order to provide recommendations balancing weight, cost, and performance. To facilitate this process, a model was developed. The model was based on interviews with design engineers and subject matter experts. The model showed the overall change in force effectiveness based on incremental increases or decreases in weight, cost ,and performance.[36] The program manager and user representative are able to use this information collaboratively in making tradeoff decisions.

An SBA approach enables early identification of the key drivers (such as cost, schedule, and performance) throughout the system's life cycle, by simulating systems and environments external to the system.[37] The Longbow Hellfire missile program eliminated its fly-to-buy criteria by the close coupling with their contractor enabled by using the Simulation/Test Acceptance Facility (STAF) to finalize the acceptance test procedures long before the production phase.[38]

The High Mobility Artillery Rocket System (HIMARS) program is an example of how valuable M&S development and reuse is becoming to program managers. The HIMARS is a multiple launch rocket system that uses a five-ton truck as its mobility platform. The HIMARS program manager decided that using M&S was the best approach for development of the HIMARS rocket launcher. No model of a five-ton truck existed, but a model was needed for integration efforts if M&S was to be used to develop the rocket launcher. The HIMARS program spent $500K of a $300M budget to build a 5-ton truck model from the Family of Tactical Vehicles (FMTV) program, and is willingly providing this model to other programs that ask for it. Other programs in the Tank and Automotive Command can now build off of this initial model to develop models of the other 24 variants of 2.5-ton and five-ton vehicles that have 85 percent commonality[39] at much less expense than if each program were to create a new model. Later on, the Military Traffic Management

Command (MTMC) used the five-ton truck model to conduct rail impact analysis during transportability testing. MTMC was also able to use the model to conduct air and ship impact analysis.[40] Users outside the Tank and Automotive community will also be able to benefit when this model is added to DMSO's MSRR, and is searchable and readily available. What started out as a requirement to model a single vehicle for one program has grown into the potential for influencing many programs and aiding the requirements of other organizations.

Many companies and programs are using a visualization room to bring team members together for the free exchange of ideas between disciplines. Although much of the work in an integrated data environment can be distributed and decentralized, a visualization room visually presents the digital data in forms that a team can use as a group. Concepts and work-in-progress can be displayed, analyzed, and debated by integrated product teams, even if they are geographically dispersed. Work can be imported electronically to conduct design reviews or to immerse a customer for feedback. The Marine Corps' Advanced Amphibious Assault Vehicle (AAAV) program has an excellent visualization room. It was built as an integral part of the entire AAAV facility, which includes government and contractor personnel. The visualization room provides the IPPD team a location to discuss issues while viewing 3-D representations of the vehicle or any component. If the team needs further clarification of an issue they can move to the adjacent high-bay area to look at a mockup or the physical prototype. This capability is invaluable for quickly and effectively resolving program issues.

In building the 777 commercial airliner, Boeing used an application called FlyThru that provides a three-dimensional view of the airplane as it is being designed. This allows errors to be detected and fixed prior to committing to expensive manufacturing processes. The fit of parts and systems on the 777 airplane was 20 times better than what had been normally achieved in the past. According to Boeing's manager of Visualization Tools, "Being able to digitally build the entire plane and see the parts of the plane before building it, was the biggest money saver for the 777."[41]

SBA Pull

SBA Pull (as we described at the beginning of the chapter) is the expectation and demand from others once they see the advantages of SBA

From program inception, the warfighter community will become an active participant in program design and development. Long before any physical prototypes are available, virtual prototypes of system concepts will be able to participate in exercises that demonstrate the battlefield effects. Logisticians will be able to quantify the cost effectiveness of making the system more supportable and work with the design team to find the most cost-effective mix of performance and support parameters. Using visualization tools such as three-dimensional solid modeling, people with real field experience can also provide real-time user feedback on design iterations, because they will be able to "see" and interact with the design as it matures.

This user feedback will begin to extend beyond the traditional service boundaries of the sponsoring organization. Programs will begin to look at how their system will interact with other systems on the battlefield by interfacing those system models on a virtual battlefield. The user will be able to begin using the new system in the expected environment and assessing any potential incompatibilities or unforeseen circumstances that could be averted in the design. Programs will be able to use each others' models to get the design information they need. The combatant commands can also be immersed at various intervals as the design matures and provide their assessment and feedback on how well the system is meeting their expectations. There will be better dialogue with the resource allocation community since the program will have much improved tools to keep the cost of the system affordable. In exploring the cost drivers over the entire system's life, they will also have much more accurate projections of the system's cost. Regardless of who is interfacing with the program, these outside agencies will have a much enhanced ability to see what the program is. Indeed, many programs noted that a significant side benefit was the great marketing tool this approach provides for visitors and oversight personnel, because program outsiders could instantly grasp the import of what they saw.

The Crusader field artillery program started a force effectiveness analysis even before the request for proposal was issued. The contractor conducted trade studies to optimize the system within the overall system, using multiple scenarios. They looked at the problems encountered (e.g. thermal analysis, ammunition capacity, reliability, maintainability, availability, etc.) in terms of cost per force effectiveness. They discovered that the Crusader could do things the current system (with upgrades) cannot. For example, the current Paladin system can not keep up with the Bradley armored personnel carrier or the M1 tank. In addition, the Crusader frees up the Multiple Launch Rocket System to hit deeper targets. In short, the Crusader increased the operational tempo of the battlefield. Some of these insights were intuitive, and some were not. The value of much of this information was difficult to explain, and the contractor was caught between satisfying the requirements stated in the request for proposal and making tradeoffs whose value to the user he could only guess at. For example, if he could decrease the size of the crew from five people down to three, what was the change in total ownership cost? Were the cost savings significant enough to justify spending money now to decrease the crew size? What were the operational tempo impacts on the Bradley and would it be able to get the necessary information quickly enough to the Crusader, which is 40 kilometers away? These are the types of issues that the requirement community needs to deal with early. The earlier in the design phase we find the answers to these questions, the better—in the past we've often not discovered these issues until operational testing, or even worse not until they're deployed to the first unit. By then we have already produced and fielded the system, when if the problem had been discovered earlier the cost to fix it would have been considerably less.

While SBA provides the capability to integrate back into the requirements generation process, it can also reach forward into the resource allocation process (the Planning, Programming, and Budgeting System), by providing total ownership cost information for the out year budgets. For example, there is an obvious extra cost associated with putting simulators on board an aircraft carrier, but it may be worth that cost to counteract deployed training atrophy.[44] SBA provides a way to explore those costs.

Even low cost demonstrations are finding it cost-effective to use a simulation-based approach. The Predator unmanned aerial vehicle advanced concept technology demonstration creatively used M&S to predict operational effectiveness and assess alternative force structure options, and thereby determined an optimum system configuration.[45]

Many programs are expanding the envelope on what's possible in SBA, and they are doing it cost-effectively. And although the tools are still limited, these programs are beginning to address the bigger implications of systems of systems issues, where in the past we did not have the ability to address them at all. Larry Winslow, Director of Technology for Boeing's Phantom Works, summed it up by saying "Now we're doing Program SBA. In the future we'll be doing Systems of Systems SBA."[46]

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6

A FUTURE STATE OF SBA

"Future commanders must be able to visualize and create the "best fit" of available forces needed to produce the immediate effects and achieve the desired results."

Joint Vision 2010

This chapter portrays the implications of an SBA approach for future defense systems acquisition, by projecting SBA capabilities and trends. While it is difficult to predict exactly *how* change will be implemented or to describe the resultant organizational structure, it is possible to envision *what* an SBA approach holds for the future. Within this acquisition process of the future, systems will be thoroughly modeled and simulated prior to "bending metal." Beginning with initial user needs, requirement definition, through design, testing, manufacturing, logistics, training, operational usage, and disposal, the synthetic environment and integrated teams will play a major role. Ideally, the acquisition process becomes a continuum without a definable beginning or end, continually assessing projected threats and needs against the ability to meet those needs. One senior acquisition official put it best when he said, "If the models are done correctly, the simulations will tell us when we need to start a new program."[1]

As the Joint Vision 2010 quotation above states, commanders must be able to project and select the best fit of systems available to accomplish their mission. This applies to not only the existing systems available today, but also to looking ahead at the deficiencies and opportunities in accomplishing future missions. SBA will provide this capability to warfighting commanders by giving them a synthetic view of future battlefields, where conceptual systems can be integrated and their operational effectiveness assessed.

In describing this future process a key assumption is that the systems acquisition process will continue to be centered on programs. The purpose of the acquisition process will be, as it is now, to produce superior systems in response to mission needs. An SBA approach will not change this product focus, but instead will enhance DoD's ability to acquire the "best fit" of new systems to meet the warfighter's needs. Some argue that in order to achieve the full potential of SBA it is necessary to move from a “product-centric” focus of systems acquisition, to a “mission-centric” view.[2] The argument is that during the earliest stages of turning a mission need into a material solution, it is necessary to have the broadest possible view in order to optimize the tradeoffs across service boundaries. This broad view could only be achieved by merging similar mission areas across the services, and divesting the services of control of the funds for these mission areas. The managers of these mission areas would have budget and decision authority to determine where best to invest funding to meet user requirements.

But just because the technology will enable the possibility of doing business this way does not necessarily make it desirable or a necessary pre-condition for implementing SBA. In fact it would be a major barrier to implementing SBA, as the services have no intention of giving up their ability to determine the requirements for the material solutions to their mission needs. This cuts to the very foundation of how the services interpret their roles and missions. There is nothing inherent about this new way of doing business that requires the services to give up their right to determine their future, so we reject the argument that implementing SBA requires a “purple,” or multi-service, acquisition corps. Instead, our assumption is that acquisition will remain in the province of each service and be program-centric. There are good reasons for maintaining separate services, and they are continuing to learn how to interoperate and function as a joint team. So too can the acquisition system.

Another assumption is that a primary objective of SBA is to get the design right before building a system, when in effect the design becomes frozen. Any changes required after the start of production result in costly engineering changes and/or system modifications. If the design is kept mostly in the synthetic environment prior to production, the cost and time required to make the change is significantly reduced. In an SBA process, the defining point is when the program moves out of the synthetic environment and begins production.

The new ability to bring systems together while they are still in design will be key to ensuring that systems will work together when they are fielded, and that they are not over- or under-designed. Competing new systems can be evaluated side-by-side on equal terms to determine the best alternative. Duplication of capability within and across Services will be more readily apparent, resulting in significant cost avoidance. According to Dr. Peter Cherry, Vice President of Vector Research, Inc., “The tools we’re using are getting better, but now we need a richer context in which to make decisions, otherwise we’ll continue to only make acquisition decisions on the margin. We make marginal decisions now—the challenge is to provide a system of systems context so we can do better than decisions on the margin. Previously we only made incremental changes program by program. Today, systems of systems require the total integration of systems. We need to be able to walk the system’s impact on the battlefield all the way from the platoon, to the company, to the battalion level. We have a lack of the full understanding of system supportability issues. We still talk about systems from the cockpit perspective—we need to elevate up to a higher level, and talk to Congress about battlefield effectiveness, not how much faster or how stealthy a system is. For example, we need to be able to show the value of the JSTARS [Joint Surveillance and Target Attack Radar System aircraft] to the artillery, not how many targets it can track and it's mean time between failure."[42]

System of systems issues are a primary concern of the Service Chiefs and the Joint Requirements Oversight Council (JROC); however, these concerns are now primarily handled at a very high level through the use of a Capstone Requirements Document (CRD). A CRD is used to identify overarching requirements for a system, or several programs that form a system of systems. It contains performance-based requirements to facilitate development of individual program requirements.[43]

Programs implementing SBA will be able to give the users the necessary insight to balance these needs and deficiencies in time to influence the design, rather than waiting for the Services and JROC to validate ever-increasing point design solutions during Milestone reviews. At this high level it's too late to impact the design cost-effectively, as all of the assumptions and tradeoff decisions have already been made in getting ready for the review. What are being presented are the results of the program optimized against the static requirements dictated in the Operational Requirements Document (ORD), which assumed the user fully understood the impact of those requirements.

With this in mind, we will start by looking at the beginning of a program. This chapter discusses a future state of SBA by looking at four major phases over the life cycle of a program, beginning with:

1. generating a mission need;
2. iterative design and development activities;
3. production; and
4. operations and sustainment.

Needs Generation Phase

SBA will encompass more than what we today call acquisition. SBA will provide a common synthetic environment that the warfighting community can use to experiment with non-material solutions to meet deficiencies, and to help them determine affordable requirements. As stated in the Chairman of the Joint Chiefs of Staff Special Instruction for the Requirements Generation System, the warfighter determines the need for a material or a non-material solution by conducting a mission area analysis of the current and projected capabilities to accomplish assigned missions. The Services' first try to satisfy mission needs through nonmateriel solutions, such as changes in doctrine or tactics. The Services will be able to use updated models and simulations provided by the SBA community as part of their mission area analysis. If a nonmateriel solution is deemed not feasible, the need is translated into a Mission Need Statement (MNS) which is expressed in broad operational terms.[3] As the MNS is documented, validated and approved, the SBA process will bring the warfighter and acquisition communities together from the very beginning of program definition. Members of the acquisition community will have a better understanding of the warfighter's need because they participated in the MNS development. Information gained from non-material experiments can provide the acquisition community insight into the warfighter's needs, and any models developed may be of use in searching for a material solution.

The generation of an MNS marks the end of the needs generation phase in the SBA process. The warfighting and acquisition communities will determine the members of the IPT who will collaborate to generate and define the operational requirements during the next phase of iterative design and development.

Iterative Design and Development Phase

The second major phase of a program in this future state of SBA is iterative design and development. As discussed in Chapter One, the early decisions in a program are critical because to a large extent they will determine system effectiveness and what the system will cost throughout its life cycle. The iterative process of determining requirements sets the stage for the TOC of the program. SBA enables the acquisition community to support the warfighters in determining affordable requirements, and provides a vehicle to get industry involved during early concept development. Rather than locking in requirements before understanding them fully, the requirements group in a program office develops simulations to conduct engineering trade studies that quantify capability versus cost. Flexibility in design is maintained as long as possible by keeping the requirements fluid until the cost impacts of each are well understood. The warfighters, industry, and program office personnel are an integrated team that makes informed decisions regarding capability versus cost issues across the entire life cycle of the system.

During this phase, models and simulations representing new and revolutionary concepts and systems are evaluated in a series of iterative "what if" trade off analyses. New concepts are evaluated in a virtual environment to determine their operational impact and system effectiveness. Cost models provide the TOC impacts of competing concepts and designs.

New conceptual models are evaluated to determine if they provide significant operational benefit, and promising concepts are developed further. As confidence in the models grows, many other issues can be addressed concurrently. Initial cost models of a design provide a rough order of magnitude (ROM) estimate of the TOC. As the design matures these ROMs are refined and become more accurate. Using an integrated visual representation of the system, functional experts on the IPPD team make their requirements and concerns known to all IPPD members, and work directly with each other in determining the optimum design. Training requirements are addressed and decisions made whether to build a stand-alone trainer or to have training embedded in the system. Logisticians and testers address supportability and testability issues and compare results between competing conceptual systems. The transportation community evaluates transportability of the system design. Manufacturing issues are addressed by designing a virtual factory. Iterations continue until a high level of confidence is reached in the design, at which time the system is submitted for a production decision. If approved, all models, simulations and data are passed on for use in producing the system.

There should be little chance of a system being disapproved during a production decision, because all stakeholders have frequent opportunities for visibility and feedback during system design. Periodic reviews of the system's progress will be possible by immersing the audience using tools such as visualization rooms. Problem areas can be resolved quickly by bringing in all stakeholders to buy off on critical affordability decisions as part of the design tradeoffs.

Oversight activities are necessary to ensure programs are producing the best possible weapons systems. Although a program will be considering systems of systems issues as part of their iterative development, there will still be macro-level issues that need to be resolved at levels higher than any one program. This oversight function will be able to consider both joint and combined systems of systems issues, for those systems that will operate with other services and allied nations.

The primary activity of the oversight function is assessing and prioritizing efforts from a system of systems perspective. It assesses the progress of programs' iterative developments and the expected production time to ensure that the system will be available when required. Programs will stay in iterative development and continue to refine the design in a synthetic environment, continually assessing new technologies as well as input from the field. A decision to begin production is made in sufficient time to allow for production, fielding, and training to occur prior to the need date. Oversight reviews will be periodic instead of activity-based, but can also be unscheduled in response to unforeseen changes in the need. These reviews will replace the current milestone reviews, because there will be minimal need for successive and increasing levels of dollar commitment as the program design matures because the dollar commitment will be significantly reduced. Instead, the ability to conduct most of the design in the synthetic environment will have the effect of fusing the activities leading up to today's present Milestone III production decision.

Production Phase

The third major phase of a program in this future state of SBA is production, which begins after a production decision is made at the end of the design and development phase. All models and simulations previously developed for a program are available for production. These models and simulations include tooling and factory design. Existing models and simulations are developed to a greater level of detail as necessary for full-scale production. As a result of previous rigorous development and validation of the models and simulations there should be:

- Minimum Engineering Change Proposals because the design coming into the Production Phase was determined acceptable to all stakeholders;

- Reduced tooling time because tooling requirements were already identified;

- Less decisions to be made because there should be few surprises and therefore less tradeoff decisions required—all known tradeoffs were evaluated and decided on;

- Better quality of the end item because reliability, maintainability, supportability, manufacturability, producibility, and other support issues were all considered and incorporated into the design;

- An affordable design because evaluation of cost models with Cost As an Independent Variable (CAIV) forced early tradeoff decisions between performance and affordability.

Operations and Sustainment Phase

The fourth and final major phase of a program in this future state of SBA is operations and sustainment, which ends upon system disposal. Actual operations and support (O&S) data are used to update the system's models and simulations. There is continuous analysis of this O&S feedback to determine future deficiencies. A deficiency may only require a system upgrade or it may require development of a totally new concept. Proposed changes to the existing models and simulations or new models and simulations to meet the deficiency are again evaluated in a synthetic environment and the warfighters can use this data to assess non-material alternatives, based upon the acquisition community's updated models. Operational units and commands could use these models and simulations to better predict their budget requirements. Cost models that reflect actual costs incurred for operations and support of the system could be used to accurately project quarterly and annual training and operational requirements.

Net Result

This proactive approach to assessing program status is driven by mission need and the date a system is required, rather than the excessive length of the acquisition cycle. Programs can be much more flexible to respond to changing mission needs, because there is not as much emphasis on locking down the requirements. The entire process is more agile because programs are able to stay in iterative development until production lead times coincide with need dates.

The ultimate effect of this new SBA process will be the ability to conduct "what if" scenarios across the entire spectrum of the DoD. Program teams will be charged with evaluating the interactions of their system(s) with other systems on the battlefield. The oversight function will be armed with the knowledge to make better informed decisions on which systems will best meet the military's needs. Program teams will have a much closer link to the battlefield upon which the systems operate, because they will be able to constantly see the battlefield effects and implications of their design decisions. All will help keep the team focused on the real goal of producing superior systems.

1. LTG George Muellner, Air Force Principal Deputy for Acquisition, interview by authors, 30 March 1998.

2. For a more complete description of this alternative view, see "Functional Description Document – 980209" developed by the NDIA's Industry Steering Group, available through the SBA Special Interest Area on-line **http://www.msosa.mil.inter.net/sia-sba/sba_sia_documents.asp?process=view_archive**

3. CJCSI 3170.01, Requirements Generation System (Formerly MOP 77)), 13 June 1997.

7

CHALLENGES TO IMPLEMENTING SBA

Many programs are making great progress in implementing SBA; however, even the best programs are a long way from implementing the ideal process outlined in the previous chapter. This chapter outlines the cultural, technical, and procedural challenges to implementing this future state of SBA. Some of these challenges will be overcome more quickly than others depending to a large extent on how much emphasis they receive. Cultural challenges result from people's views, beliefs, and management actions; technical challenges result from M&S limitations in technology; and process challenges are caused by the way the DoD is organized and operates.

Cultural Challenges

Many people maintain that cultural barriers are the biggest challenge to overcome in moving to an SBA process. These challenges include acceptance of M&S, not believing everything seen, working as teams in a distributed environment, and becoming proactive in determining an affordable design.

Acceptance of the results of M&S is probably the single biggest challenge, as it involves a significant change in the way DoD does business. There is a natural resistance to changing the old ways if they appear to be working. There is significant resistance to believing in virtual prototypes, as people are more apt to believe one physical test versus thousands of virtual tests. For example, the technology for simulating the crashworthiness of a vehicle far outpaces the acceptance of the results, to the point where their accuracy is better than the variability between different physical crashes.[1] However, despite this capability, all automobile manufacturers continue to conduct expensive crash tests (albeit they are conducting much fewer tests than in the past). A culture change is required to view computer modeling as analogous to physical modeling. Even so, acceptance of M&S is occurring at an increasing rate as M&S is successfully implemented. The engineers frequently resist using M&S at first, but soon discover that it can be a very valuable design tool, and that they often do not need hardware to find problems.

An important corollary to this acceptance problem is to "not believe everything you see." Simulations create compelling visual arguments that can drive complacency in questioning the underlying models. The mere fact that something can be modeled and simulated does not mean that it can be built. A rigorous process of verifying, validating, and accrediting (VV&A) models and simulations for their intended purpose can counteract this problem, and can increase the level of confidence that the models and simulations are representative of what was intended and accurately represent reality.[2]

Another cultural challenge is learning how to work as teams in distributed environments. Western culture and training places an emphasis on individual performance, but systems are designed and built by teams. An SBA process can accentuate this long-standing problem because even more emphasis is placed on working together as a team, and the teams may change frequently and not be co-located. Many companies are experimenting with ways to create just-in-time teams and reward team performance.

A final cultural challenge is learning to become proactive in designing an affordable system. This involves continually refining the requirements with the user to find the optimum mix of performance and affordability, and looking at the costs across the entire life of the system. The range of options to explore can be intimidating, and the tendency will be to move on with a design that appears good enough, rather than continuing to explore design options to reduce the TOC of the system.

Technical Challenges

Technical barriers are perhaps the easiest to envision. Technical challenges include interoperability concerns, and limitations in what can be effectively and affordably modeled.

Interoperability challenges result from the desired ability to seamlessly share models and simulations between programs and across services to analyze tradeoffs in a system of systems synthetic environment. As discussed previously, the DMSO is pursuing various initiatives in the Common Technical Framework to facilitate interoperability and reuse. Certainly more technical improvements will continue emerging, such as computer-aided tools, which will facilitate the development and deployment of reuse standards and policies such as the High Level Architecture.

Programs can experience interoperability challenges within their own program, as they attempt to move information up and down the hierarchy of models and simulations (for example, from campaign to mission to engagement to engineering, and then back up). There are interoperability challenges in making different tools communicate with each other, particularly those that were developed for use in a different context from the one for which they are now intended. For example, a logistics model that helps determine the optimum stockage level for spare parts may not be compatible with another tool that predicts reliability, or even worse, gives conflicting results.

The MSRR will provide increasing access to programs to assist in their finding what models and simulations are available for their systems of systems analyses, which will facilitate maximum reuse. This is particularly evident with items that have been designed for reuse, such as threat and environment data. However, designing for reuse costs approximately three times as much as designing for a specific program,[3] and is only feasible when all of the programs intending to use the models and simulations are known in advance. HLA begins to solve this problem by helping groups that choose to interact with each other define specific system architectures called federations. This creates a problem when a program wants to use another program's model or simulation that was developed as part of another federation. An extreme but probable example would be attempting to use models and simulations from several other federations to get a true picture of the battlefield.

In an ideal SBA process, models and simulations can be reused as easily as using a library or repository. However, historically this type of ad hoc reuse has only resulted in about 20 percent savings in software code reuse.[4] A lot of time is often spent analyzing the code to determine what is applicable for reuse, and often the most valuable results are the insights gained into how to functionally design the new code, rather than the reuse of the code itself. A SBA process may not actually reuse models and simulations in this traditional software sense, but it does point out the considerable difficulty experienced in a similar process which is much simpler than SBA envisions.

Some of the easiest areas of reuse to envision are for common areas that many programs will need, such as models of the environment in which systems will operate, and of the threats these systems will face. Efforts are already ongoing in some of these areas, such as the SEDRIS effort mentioned earlier, and the Virtual Proving Ground under development at the Army's Test and Evaluation Command. The DoD has a vested interest in reducing duplication of efforts in these areas, and also in having a common depiction of them across all systems. Programs will be able to use the DoD's environment to evaluate many aspects of their system. If a program has a requirement that is not satisfied by the common environment, it can be expanded to meet the needs, and it can be subsequently brought back into the aggregate common environment for reuse by other programs. The common environment gets expanded as a result. Having a common environment will also provide credibility and help to minimize issues that could arise if each contractor developed his own environment and threat models, especially if these systems were in a competitive selection process. Other items the DoD should consider providing are the analytical tools that will be used to evaluate contractors' models. For example, if the DoD planned to use a constructive model such as the Army's CASTFOREM (Combined Arms and Support Task Force Evaluation Model) to evaluate a contractor's proposed model, then the program office should consider providing CASTFOREM to the contractor early in the program.

There are also technical limitations in what can be effectively and affordably modeled, including reliable cost figures, failure and reliability prediction, and human behavior. Cost models that accurately project TOC need to be available as early as possible to enable informed tradeoff analyses that all communities and decision makers can believe. Discrepancies will otherwise persist between cost estimates prepared by differing agencies—for example, the Government Accounting Office might predict higher cost estimates than the program's estimates. These discrepancies could effectively cripple the program's ability to design a more affordable system, because the credibility of the system's total ownership costs that are being used to make design tradeoffs is called into question. Cost curves for each alternative considered allow quantification of alternatives and operational tradeoffs with cost as an independent variable. The objective is to use modeling and simulation to help determine the “bend in the knee” when looking at performance versus cost. This bend in the knee refers to the point where the cost of providing greater performance begins to exceed the benefit it provides, or its point of marginal return. By showing the user where the bend in the knee starts to occur on a given performance characteristic then we can ask if it is worth the extra cost to achieve the incrementally less capability per dollar spent. The earlier we are able to show the user the cost implications of his requirements, the sooner we can agree to the necessary tradeoffs to result in an affordable design. This forces the user to make tough calls early in the system’s development and avoids pursuing unaffordable solutions.

We need to be able to treat CAIV at the earliest stages, by incorporating cost considerations into the computer-aided design and engineering tools. It is otherwise impossible to get cost on the table as a trade mechanism. We are still using cost models that use dollars per pound as the basis of estimating, as opposed to conducting detailed cost tradeoffs. Just as computer-numerically-controlled (CNC) machines are able to manufacture items directly from the digital design data, cost models would be able to directly use the digital data to project manufacturing costs. Even more sophisticated cost models would be able to address costs across the life cycle of the system—operations costs, upgrade costs, maintenance costs, and disposal costs, for example.

Today’s state-of-the-art in modeling and simulation does not provide the ability to fully and accurately predict failures to the point where we can replace physical reliability testing with reliability testing using modeling and simulation. Durability algorithms are in short supply, because of the complexity of durability models. The ability to predict failure varies from one product area to another. Physics of failure is farthest along in electronics.[5] For example, transistor manufacturers are able to predict with high confidence when transistors will fail. In chips, we know exactly how they’ll function and how they’ll behave, but the same does not hold for the mechanical world. Currently, we do not have good models for predicting failure and determining reliability of mechanical systems or their components. The ability to predict the failure of a *new* system requires an understanding of the internal physics of the materials within the system. The ability to model this level of fidelity within components and within a system is in its infancy, but some fields of study are making strides by applying recent increases in computing power. Meteorological experts are beginning to model weather systems at increasing levels of fidelity to achieve a better understanding of how thunderstorms, hurricanes, and tornadoes behave. Pharmaceutical companies are beginning to model new drugs at the atomic level and then immerse themselves into the model to help them create the drug. We can expect similar advances in other fields as the technology matures. We need to develop physics of failure and cost models to help predict reliability through simulation. If, in simulation, we are able to test a program to the point of failure, then we can improve overall system reliability by improving the area that failed. We can also use these failure data to predict the required maintenance, manpower, spares, and life cycle cost for a system given the number of operating hours.

The limitations to our ability to build high fidelity physics of failure models result from such things as the limited understanding of how materials fail, variations in the manufacturing processes of materials, and variations in the properties of materials. One of the most significant limitations is the cost and time required to capture all the stress loads that a system or component will experience during operations. Each test conducted on a system captures data for only one set of operational conditions. Program schedule and cost constraints limit the number of samples that can be taken, so assumptions are necessary to extrapolate from this limited sample size to make conclusions for all possible conditions that may be experienced. If we could accurately model the physics of the system, we could conduct many more tests in the synthetic environment than are cost-effective with today's approach.

A program manager must demonstrate that the system he is developing will meet the reliability required by the user. Durability testing is the process that provides the evidence of whether a system is reliable enough to proceed toward production. Durability testing is very demanding of program resources, requiring the PM to schedule and pay for hundreds, if not thousands of hours of system operations and testing. Confidence in the reliability of the systems that we field requires that we have an acceptable level of understanding about why and how often a system will fail, which can be a significant cost driver of a program.[6] The challenge is to reduce the number of reliability testing hours required. If we can reduce the number of reliability testing hours required of an end item, we can reduce both the schedule and budget necessary for a program during this phase. As an example, the M1A2 tank program dedicated four physical prototype vehicles just to support durability testing.[7]

Today, when we develop a new system it has no known reliability.[8] Only through use and time do we achieve reliability. The only true way to achieve this knowledge is to run the physical system. When we do this we gain confidence in the reliability of that one system we tested and then we infer reliability to any system that is built to the same specifications. Therefore, the two critical factors are first, that the prototype we test be in accordance with the system's specifications; and second, that we are able to accurately repeat builds of subsequent systems. The weakness of this approach is that the physical prototype is likely to have flaws and inconsistencies compared with the final production version of the system because of human error in building the prototype, and configuration changes as we gain more knowledge about the system and as technology continues to develop.

Modeling and simulation actually enables us to improve the confidence in the ability to accurately build and test a prototype that is truly representative of a production item. Using M&S we are able to keep the design open to changes longer because we have greater confidence that the final design will meet the required need and that the production run will be successful. This means we need less time allocated for last minute changes and gives us more time to learn about the system as it matures, to incorporate lessons learned back into the system, and to integrate the latest technology if desired. The changes made using M&S early in the design can be much less expensive than if we were making changes to a physical prototype, which would not be possible until much later in the program.

A final technical limitation is human behavior modeling. Conceptually, SBA could include modeling and simulating the acquisition process itself to help produce better acquisition strategies. Human behavior is difficult to model, however, because our assumptions cannot be correct for all individuals. Some factors that influence how an individual will react in a given situation include experience, education, values, self-confidence, and fatigue. The variability in reactions is so great that accurately predicting behavior is not possible and any process, such as acquisition, that is heavily dependent on human interface and decisions is difficult to predict and model. Probably the best we'll be able to achieve in this area will be through the use of wargaming techniques. Wargaming allows for shortfalls in models and data, and provides a way for program managers to simulate interactions with entities that cannot be directly controlled. The insights gained by understanding the implications of decisions should enable managers to develop more effective strategies.[9]

Process Challenges

Process challenges result from the way DoD operates and is organized, and include the change in the test process, security of classified and proprietary data, and metrics.

A major concern of program managers is the cost and time required to test a system. A significant portion of a program's schedule and budget is usually allocated for testing, and an SBA approach has the potential of reducing both. As mentioned earlier, the role of testing is no longer to validate point designs; rather the role of testing is to validate models so that there is a high confidence in the resultant simulations from those models. Test personnel should be members of the IPT during the earliest stages, and should work with the developer to consider and resolve test issues. A good example of addressing test issues early is the Follow On To TOW (Tube-Launched, Optically Tracked, Wire Guided) hand-held anti-tank missile, or FOTT. In the FOTT program the specifications for the Virtual Proving Ground were included in the Request for Proposal, and test personnel were co-located with the program developers.[10] These test personnel grew up with the models and matured them with tests as required to gain confidence in their use. They also helped develop the acceptance test procedures (ATP), so that many iterations and excursions could occur quickly and inexpensively and the results could be checked against the ATP after each iteration. Involving developmental test and operational test personnel early in the program and using M&S to gain higher confidence in the first missile allowed the FOTT PM to reduce missile requirements for engineering and manufacturing development (EMD). The Javelin program (a similar fire-and-forget missile) required 190 missiles for EMD, while FOTT required only 40 missiles.[11]

Within the test community there needs to be a shift in focus from testing hardware to testing simulations of hardware. By testing simulations of future hardware systems, IPT members can resolve many problems before expensive prototypes are built. Test simulations help to identify the problem areas where efforts should be focused to increase the probability that live testing is successful. The knowledge gained from conducting these simulations will lead to better quality testing as well as more efficient and less testing of the physical hardware. As an example, during the Longbow helicopter Hellfire missile development there were more than 500 simulated firings and only

20 live shots. This resulted in the Longbow Simulation/Test Acceptance Facility (STAF) paying for itself in one year, with several years left in the program.[12] In addition, other programs will be able to "reuse" the facility, further amplifying the cost avoidance for DoD.

The purpose of conducting live testing is changing from validation of the physical system to validation of the model. General Motors is using tests to validate model design assumptions and not to find fixes. The goal is to get the design right as early in the life cycle as possible.[13] As confidence in the results of models goes up the number of live tests required will come down. Any questions that simulations cannot answer may require a physical prototype of the subsystem in question to reduce risk to an acceptable level. Information gained from building and testing any physical prototype of the system should be used to update the system's model.

A big challenge is to have an authoritative DoD source for a common synthetic test environment. If we intend to compare competing system designs, we need to ensure we evaluate those systems within a common synthetic environment that is also available to the system developers. This common environment is required to provide a level playing field for evaluating conceptual designs of a system. These relationships are critical in ensuring that the run-time databases, derived from the synthetic environment database, will be correlated so that all "views" of the environment are the same. An important "view" is that of computer-generated forces that do not "see" the battlefield but must use the data representations to correctly interpret the environmental conditions.[14] This means that the computer controlling the actions of military forces in a simulation needs information about the terrain and objects in the environment represented in a way it can interpret. For example, the visual representation of an object that a soldier-in-the-loop needs during a simulation is no good to the computer. The computer needs information about the same terrain and objects, but numerically represents the essential information, such as position, height, weight, etc. Unfortunately, synthetic environment data interchange today is cumbersome, expensive, and often unreliable.

A second major process concern among government and industry is ensuring the security of classified and proprietary data. If we expect agencies and companies to provide data through repositories, we must be able to provide a high level of confidence in the security of those data. We want data to be readily available and shared with those who need the information and at the same time, we must keep data from those who do not have a need to know. Today's technology allows us to share data easily and there are many ways that data can get into the wrong hands. As an example, an automobile manufacturer inadvertently left some data of a "next generation" vehicle on a data tape that was reused and given to one of its suppliers. The supplier inadvertently passed the data on to a competitor. This security breach of corporate knowledge allowed the competition to make up a year-and-a-half in development time.[15]

Program offices are also very careful about who uses the models and simulations of their program. They want to know exactly how and for what purpose the data will be used. This is understandable because a competing program could use the detailed information provided by the models and simulations of another program to show how its system is superior or where the other program is deficient. The information contained in a model could also be a valuable source to determine vulnerabilities of the new system.

A final process challenge will be developing metrics, which are needed for an overall assessment of progress in the execution of a program. Metrics are measures of success that serve as a powerful management tool for evaluating effectiveness in accomplishing project objectives and in achieving and improving customer satisfaction.[16] They allow program managers to manage on the basis of facts and data. Metrics solely focused on individual process results do not give a picture of overall success in implementation. Metrics, therefore, should also be structured to identify the overall effects of SBA implementation. Measures that could be used to gauge success include schedule, responsiveness and timeliness, and communications. The measurement of variances between planned and actual schedules, consumption of resources, productivity, customer satisfaction, cycle time, and completion of tasks could be particularly useful in determining if a program is capturing the expected benefits and cost avoidance. In a collaborative, concurrent, and distributed engineering environment, communications takes on an increasingly important role. Organizations must be able to easily and quickly move large amounts of data. They must track how well information is moving through the organization, such as whether the Product Information Manager is facilitating concurrent engineering, or whether the engineers are experiencing unacceptable delay times.

There are difficult cultural, technical, and procedural challenges to implementing the ideal SBA process of the future. But we don't have to wait until all the challenges are solved before we start implementing those parts where we can extract value. The process is beginning to change, and those who adapt will find the biggest rewards.

1. Stefan Thomke, "Simulation, Learning and R&D Performance: Evidence from Automotive Development," *Research Policy* 27 (1) (May 1998).

2. See "DoD VV&A Recommended Practices Guide," Defense Modeling and Simulation Office, November 1996, for detailed information on VV&A.

3. James Shiflett; Vice President, SAIC; interview by authors, 20 March 1998.

4. LTC Gene Glasser, U.S. Army; Director, Army Software Reuse Center, interview by authors, 7 May 1998.

5. Jerry Chapin, U.S. Army Tank and Automotive Command, interview by authors, 25 February 1998.

6. Art Adlam, U.S. Army Tank and Automotive Command, interview by authors, 25 February 1998.

7. Robert Lentz, General Dynamics Land Systems, interview by authors, 24 February 1998.

8. David Chang and Prakash Shrivastaka, General Motors, interview by authors, 31 March 1998.

9. For an innovative approach to using wargaming in acquisition, see on-line **http://www.npt.nuwc.navy.mil/divnewport/Business-War-Games/main.html.**

10. John Haug, Director, Technical Mission, TECOM, interview by authors, 11 February 1998.

11. John Bier, Technical Management, Close Combat Anti-Armor Weapon System program office, phone interview, 8 September 1998.

12. Brigadier General Robert E. Armbruster, Deputy for Systems Acquisition, U.S. Army Aviation and Missile Command, remarks during presentation at Army SBA Conference, Orlando, FL, 21-22 January 1998.

13. David Chang and Prakash Shrivastaka, General Motors, interview by authors, 31 March 1998.

14. **http://www.sedris.org/doc_trpl.htm**

15. Unnamed source due to confidentiality.

16. Many of the ideas expressed here were inspired by the "DoD Guide to Integrated Product and Process Development," Office of the Under Secretary of Defense (Acquisition and Technology), 5 February 1996.

8

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides our conclusions regarding SBA, along with some recommendations on where to proceed. Our conclusions are that SBA is a smarter way of doing business, but there are significant challenges ahead to realizing its full potential. Our recommendations are:

- educate the workforce on this new concept;
- encourage a single SBA process for DoD;
- identify SBA efforts within program documents;
- continue developing the tools and infrastructure to make it happen;
- fund SBA as well as M&S development; and
- conduct a follow-on study that results in an SBA Recommended Practices Guide.

Conclusions

SBA is a smarter way of doing business. It creates an environment where complex issues can be integrated and evaluated to support decision makers throughout the life cycle of a program. Risks can be identified, minimized, mitigated, or even eliminated to increase the probability of program success. Products developed when implementing SBA can serve as excellent communication and marketing tools. Being able to visualize a system as it evolves from a low fidelity concept into a high fidelity system is very useful in resolving conflicts throughout development. Simulation and visualization are powerful tools for IPTs and decision makers which allow them to see the results of each decision and evaluate the ramifications before having to make a costly final decision.

Using SBA, programs are making decisions based not only on more information, but also better information, which is leading to a better product. These programs are being “pushed” into using SBA for a variety of reasons, but once there, they are finding many benefits. Both industry and government programs are turning to SBA as a means of remaining competitive and making the most of limited funds. Companies that have implemented SBA on one program have started to apply SBA to other programs and are looking for ways to leverage efforts across programs. Many programs are discovering that using M&S is the only way to accomplish certain tasks because of cost, safety, time, or scale considerations. As decision makers and users begin to see programs implementing SBA, there will be a "pull," or an expectation that SBA will be used in other programs. As they are shown the cost impacts, warfighters are beginning to see an impact and the value of delaying the finalizing of their requirements. Programs using SBA will be perceived as better and in fact will *be* better, than programs not using SBA. SBA will enable programs to quickly determine what the issues are and to focus on them. Not only will the program benefit from implementing an SBA approach, but outside organizations will benefit also.

The roles of industry and DoD are unclear for implementing SBA, however. There is uncertainty about who should make the first move toward institutionalizing SBA. In the spirit of the Single Process Initiative to follow best commercial practices, DoD is reluctant to dictate to industry how to implement SBA, believing that it will occur naturally in the competitive commercial world. Industry's attitude, on the other hand, is that if DoD wants a standard system, it will have to put some money behind development.[1] Industry is particularly concerned that each service will come up with different standards and ways to implement SBA.

As discussed in the last chapter, there are technical, process, and cultural challenges to implementing SBA. The technical challenges are impeding the full potential of SBA, but are continuing to improve at various paces among the domains. SBA will continue to pick up speed and move toward a critical mass as these barriers continue to fall. The process challenges require further analysis and study. SBA provides a significantly different approach to identifying and meeting military requirements from the current process. The implications of a collaborative, concurrent development approach versus the present sequential, increasing buy-in approach are not well understood, and may require us to reevaluate our current process. Activities within the process may need to occur more often or at a different time in the development of a system. The cultural challenges require education and experience—education to spread the word on this new perspective on using M&S, and experience that comes by getting started and learning with a new process. Many programs are doing smart things and there is a great need for educating all SBA stakeholders about what SBA is and how it is different from just using M&S in a program. Acceptance of SBA will continue to grow as more people learn its concept, capabilities, and benefits. Gaining experience with SBA is one of the best ways of overcoming cultural barriers.

Recommendations

Our first recommendation is to educate the workforce on the new SBA concept by incorporating classes on SBA into the curriculum at the Defense Systems Management College that define what SBA is, what tools are available, what SBA efforts are ongoing, and what the vision of SBA is. These classes should also include lessons learned by programs that successfully implemented SBA as well as from programs that failed to implement SBA. As noted earlier, there is only a single reference to SBA in the Defense Acquisition Deskbook. Some of the areas that are now devoted to M&S should be reviewed with the goal of incorporating the broader viewpoint of using an SBA approach in acquisition, rather than just the use of M&S. Once this happens, the field should be encouraged to provide input on best practices, and wisdom and advice. To get the dialogue started, we recommend that this book be included in the Deskbook as a reference source for SBA.

Our second recommendation is to encourage all stakeholders to define and develop a single DoD SBA process. The Services need to work together to develop an agreed upon single process for SBA. A single process will reduce the burden on contractors when dealing with multiple Services. The result should be a reduction in the overall cost to DoD across programs. Certainly we don't want a situation that replicates the one in some industries that dictate specific software packages for their suppliers.

Our third recommendation is to identify SBA efforts within existing program documents, such as the Simulation Support Plan, the Test and Evaluation Master Plan, and the Single Acquisition Management Plan. The intent is to move beyond just specifying how M&S will be used in a program, to outlining how M&S will be applied to change the process to an SBA approach.

Our fourth recommendation is to continue developing the tools and infrastructure to enable programs to conduct systems of systems analyses. The DoD should continue to look for investments in common SBA tools that will support analysis of programs within a system of systems synthetic environment. DoD needs to find the resources to develop common portions of the SBA infrastructure, as this issue is too big and too important to leave to a piecemeal approach by individual programs, which cannot afford to fund large-scale M&S efforts to benefit all programs. Programs do only what is required to successfully field a system. A program may develop a capability that all may benefit from, but this is secondary and not the focus of the program. Common tools developed by a program or by DoD need to be available to other programs.

Our fifth recommendation is to fund SBA development in addition to M&S development activities. Efforts need to focus on achieving the holistic view of SBA and not on individual and unrelated M&S activities. The bigger picture of SBA must be emphasized and efforts coordinated to optimize their contribution to achieving SBA. When screening priorities for funding, use an SBA filter as well as an M&S filter.

Our sixth and final recommendation is to conduct a follow-on study to analyze the impacts of SBA on cost, schedule, and performance, and from that develop an *SBA Recommended Practices Guide.* While we concentrated our efforts on the success stories and programs that touted prowess in implementing SBA, there are probably failures and lessons learned the hard way. Some of these may be the result of technology limitations, while others are errors in implementation, but they are all valuable lessons. This effort should focus on the hard evidence to show why SBA is indeed a better, faster, and cheaper way of doing business, and thereby ferret out the key criteria programs should use in determining how to implement SBA in their program.

ENDNOTES

1. Bill Gregory, "Simulation's Latest Promise," *Armed Forces Journal International,* June 1998, Volume 135, Number 11, p.34.

APPENDIX A

ACRONYMS AND GLOSSARY

APPENDIX A
ACRONYMS AND GLOSSARY

ACRONYMS

Acronym	Term
AAAV	Advanced Amphibious Assault Vehicle
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ADS	Authoritative Data Sources
AI	Artificial Intelligence
APMC	Advanced Program Managers Course
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAD	Computer Aided Design
CAE #1	Component Acquisition Executive
CAE #2	Computer Aided Engineering
CAIV	Cost as an Independent Variable
CAM	Computer Aided Manufacturing
CASTFOREM	Combined Arms and Support Task Force Evaluation Model
CEP	Concept Evaluation Program
CFD	Computational Fluid Dynamics
C4I	Command, Control, Communications, Computers, and Intelligence
CMMS	Conceptual Model of the Mission Space
CNC	Computer-Numerically-Controlled
CODE	Common Operating Digital Environment
CRD	Capstone Requirements Document
CTF	Common Technical Framework
DIF	Data Interface Format
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DRA	Decision Risk Analysis
DS	Data Standards
DSAC	Defense Systems Affordability Council

DSMC	Defense Systems Management College
DT&E	Developmental Test and Evaluation
EMD	Engineering and Manufacturing Development
EXCIMS	Executive Council for Modeling and Simulation
FMTV	Family of Tactical Vehicles
FOTT	Follow-On To TOW
HIMARS	High Mobility Artillery Rocket System
HITL	Human-in-the-Loop
HLA	High Level Architecture
HWIL	Hardware in the Loop
ICD	Interface Control Document
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
JIMM	Joint Interim Mission Model
JMASS	Joint Modeling and Simulation System
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance and Target Attack Radar System
LCC	Life Cycle Cost
LCM	Life Cycle Management
LFT&E	Live Fire Test and Evaluation
LRIP	Low Rate Initial Production
MAIS	Major Automated Information System
MDAP	Major Defense Acquisition Program
MNS	Mission Need Statement
MOE	Measures of Effectiveness
MOO	Measures of Outcome
MOP	Measures of Performance
M&S	Modeling and Simulation
MSIP	Modeling and Simulation Investment Plan
MSOSA	Modeling and Simulation Operational Support Activity
MSRR	Modeling & Simulation Resource Repository
MTMC	Military Traffic Management Command
NDIA	National Defense Industrial Association

O&S	Operations and Support
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
PIM	Product Information Management
PM	Program Manager
PPBS	Planning, Programming, and Budgeting System
QFD	Quality Functional Deployment
ROM	Rough Order of Magnitude
SBA	Simulation Based Acquisition
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SES	Simulate, Emulate, Stimulate
SIPRNET	Secret Internet Protocol Routing Network
SISO	Simulation, Interoperability, and Standards Organization
SMART	Simulation and Modeling for Acquisition, Requirements and Training
STAF	Simulation Test Acceptance Facility
STEP #1	Simulation, Test, and Evaluation Process
STEP #2	Standard for the Exchange of Product Data
SWIL	Software in the Loop
TCO	Total Cost of Ownership
TOC	Total Ownership Cost
TOW	Tube-Launched, Optically-Tracked, Wire-Guided
VERT	Venture Evaluation Review Technique
VV&A	Verification, Validation, and Accreditation

GLOSSARY

Accreditation

The official certification that a model or simulation is acceptable for use for a specific purpose. (reference *DoD M&S Glossary*)

Advanced Concept Technology Demonstration

Technology demonstrations that are tightly focused on specific military concepts and that provide the incorporation of technology that is still at an informal stage into a warfighting system. The ACTDs have three objectives: a) to have the user gain an understanding of and to evaluate the military utility of concepts before committing to acquisition; b) to develop corresponding concepts of operation and doctrine that make best use of the new capability; and c) to provide the residual operational capability to the forces. ACTDs are of militarily significant scope and of a size sufficient to establish utility.(reference *DoD M&S Glossary*)

Aggregation

The ability to group entities while preserving the effects of entity behavior and interaction while grouped. (reference *DoD M&S Glossary*)

Algorithm

A prescribed set of well defined, unambiguous rules or processes for the solution of a problem in a finite number of steps. (reference *DoD M&S Glossary)*

Artificial Intelligence

The effort to automate those human skills that illustrate our intelligence e.g., understanding visual images, understanding speech and written text, problem solving and medical diagnosis. (reference *DoD M&S Glossary*)

Battlespace

Refers both to the physical environment in which the simulated warfare will take place and the forces that will conduct the simulated warfare. All elements that support the front line forces (e.g., logistics, intelligence) are included in this definition of battlespace. (reference *DoD M&S Glossary*)

Benchmark

The activity of comparing the results of a model or simulation with an accepted representation of the process being modeled. (reference *DoD M&S Glossary*)

‘bend in the knee’

Refers to the point where incremental increases in performance are obtained at ever increasing costs, or the point of diminishing returns.

Common-Use M&S

M&S applications, services, or materials provided by a DoD Component to two or more DoD Components. (reference *DoD M&S Glossary*)

Component

(See "DoD Component")

Computational Fluid Dynamics

The accurate numerical solution of the equations describing fluid and gas motion and the related use of digital computers in fluid dynamics research. (reference *DoD Mission Success from High Performance Computing,* DoD HPCMO Report, Office of the Secretary of Defense, DDRE, March 1995)

Computer Simulation

A dynamic representation of a model, often involving some combination of executing code, control/display interface hardware, and interfaces to real-world equipment. (reference *DoD M&S Glossary)*

Conceptual Model of the Mission Space

First abstractions of the real world that serve as a frame of reference for simulation development by capturing the basic information about important entities involved in any mission and their key actions and interactions. They are simulation-neutral views of those entities, actions, and interactions occurring in the real world. (reference *DoD M&S Glossary*)

Constructive Model or Simulation

Models and simulations that involve simulated people operating simulated systems. Real people stimulate (make inputs) to such simulations, but are not involved in determining the outcomes. Constructive simulations are often referred to as war games. (Note: Also see additional information under "Live, Virtual, and Constructive Simulation.") (reference *DoD M&S Glossary*)

Cost as an Independent Variable

Methodologies used to acquire and operate affordable DoD systems by setting aggressive, achievable lifecycle cost objectives, and managing achievement of these objectives by trading off performance and schedule, as necessary. Cost objectives balance mission needs with projected out-year resources, taking into account anticipated process improvements in both DoD and industry. CAIV has brought attention to the government's responsibilities for setting and adjusting lifecycle cost objectives and for evaluating requirements in terms of overall cost consequences. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Decision Risk Analysis

A methodology that quantifies and ties together cost, schedule, performance, producibility, risk, and quality to permit tradeoffs.

DoD Component

One of the four services within the Department of Defense, i.e. Army, Navy, Air Force, or Marine Corps.

Domain

The physical or abstract space in which the entities and processes operate. The domain can be land, sea, air, space, undersea, a combination of any of the above, or an abstract domain, such as an n-dimensional mathematics space, or economic or psychological domains. (reference *DoD M&S Glossary*)

Emulate

To represent a system by a model that accepts the same inputs and produces the same outputs as the system represented. For example, to emulate an 8-bit computer with a 32-bit computer. (reference *DoD M&S Glossary*)

Emulation

The imitation of a computer system, performed by a combination of hardware and software, that allows programs to run on systems that would normally be incompatible. (reference **http://www.wcom.com/cgi-bin/dictQuery.cgi?key=emulation**)

Entity

A distinguishable person, place, unit, thing, event, or concept about which information is kept. (reference *DoD M&S Glossary*.)

Enterprise

An arbitrarily-defined functional and administrative entity that exists to perform a specific, integrated set of missions and achieve associated goals and objectives, encompassing all of the primary functions necessary to perform those missions. An intranet, for example, is a good example of an enterprise computing system. (reference http://www.pcwebopaedia.com/TERM/e/enterprise.html)

Environment

The texture or detail of the natural domain, that is terrain relief, weather, day, night, terrain cultural features (such as cities or farmland), sea states, etc.; and the external objects, conditions, and processes that influence the behavior of a system (such as terrain relief, weather, day/night, terrain cultural features, etc.). (reference *DoD M&S Glossary*)

Executive Council for Modeling and Simulation

An organization established by the USD(A&T) and responsible for providing advice and assistance on DoD M&S issues. Membership is determined by the USD(A&T) and is at the Senior Executive Service, flag, and general officer level. (reference *DoD M&S Glossary*)

Federate

A member of a High Level Architecture Federation. All applications participating in a Federation are called Federates. This may include federation managers, data collectors, real world ("live") systems (e.g., C4I systems, instrumented ranges, sensors), simulations, passive viewers and other utilities. (reference *DoD M&S Glossary*)

Federation

A named set of interacting federates, a common federation object model, and supporting Runtime Infrastructure, that are used as a whole to achieve some specific objective. (reference *DoD M&S Glossary*)

Fidelity

The accuracy of the representation when compared to the real world. (reference *DoD M&S Glossary*)

Hierarchy

A ranking or ordering of abstractions. (reference *DoD M&S Glossary*)

High Level Architecture

Major functional elements, interfaces, and design rules, pertaining as feasible to all DoD simulation applications, and providing a common framework within which specific system architectures can be defined. (reference *DoD M&S Glossary*)

Human Factors

The discipline or science of studying man-machine relationships and interactions. The term covers all biomedical and psychological considerations; it includes, but is not limited to, principles and applications in the areas of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation. (reference *DoD M&S Glossary*)

Human-in-the-Loop

A model that requires human interaction. (reference *DoD M&S Glossary*)

Infrastructure

An underlying base or foundation; the basic facilities, equipment, and installations needed for the functioning of a system. (reference *DoD M&S Glossary*)

Integrated Product and Process Development

An approach to systems acquisition that brings together all of the functional disciplines required to develop, design, test, produce and field a system. This is essentially the same as Concurrent Engineering. (reference *DoD M&S Glossary*)

Integrated Product Team

Integrated Product Teams are a means to achieve concurrent engineering or Integrated Product and Process Development. They are multi-disciplinary teams consisting of representatives from all disciplines involved in the system acquisition process, from requirements development through disposal. Having the participation of all the appropriate disciplines, Integrated Product Teams are often empowered to make decisions to achieve successful development of their particular product. (reference *DoD M&S Glossary*)

Interoperability

See: M&S Interoperability.

Life Cycle Cost

The total cost to the government of acquisition and ownership of that system over its useful life. It includes the cost of development, acquisition, operations and support (to include manpower), and where applicable, disposal. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Live Simulation

A simulation involving real people operating real systems. (Note: Also see additional information under "Live, Virtual, and Constructive Simulation.") (reference *DoD M&S Glossary*)

Live, Virtual, and Constructive Simulation

The categorization of simulation into live, virtual, and constructive is problematic, because there is no clear division between these categories. The degree of human participation in the simulation is infinitely variable, as is the degree of equipment realism. This categorization of simulations also suffers by excluding a category for simulated people working real equipment (e.g., smart vehicles). (Note: also see each term separately, e.g., live simulation) (reference *DoD M&S Glossary*)

M&S Infrastructure

M&S systems and applications, communications, networks, architectures, standards and protocols, and information resource repositories. (reference *DoD M&S Glossary*)

M&S Interoperability

The ability of a model or simulation to provide services to and accept services from other models and simulations, and to use the services so exchanged to enable them to operate effectively together. (reference *DoD M&S Glossary*)

Maintainability

The ability of an item to be retained in, or restored to, a specified skill level, using prescribed procedures and resources, at each prescribed level of maintenance and repair. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Mathematical Model

A symbolic model whose properties are expressed in mathematical symbols and relationships; for example, a model of a nation's economy expressed as a set of equations. Contrast with: graphical model; narrative model; software model; tabular model. (reference *DoD M&S Glossary*)

Measures of Effectiveness (MOE)

A measure of operational success that must be closely related to the objective of the mission or operation being evaluated. A meaningful MOE must be quantifiable and measure to what degree the real objective is achieved. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Measures of Outcome (MOO)

Metrics that define how operational requirements contribute to end results at higher levels, such as campaign or national strategic outcomes. (reference *M&S Report, DSMC 1994 Research Fellows Report*)

Measures of Performance (MOP)

Measures of the lowest level of performance representing subsets of measures of effectiveness (MOEs). Examples are speed, payload, range, time on station, frequency, or other distinctly quantifiable performance features. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Metadata

Information describing the characteristics of data; data or information about data; descriptive information about an organization's data, data activities, systems, and holdings. (reference *DoD M&S Glossary*)

Metric

A measure of the extent or degree to which a product possesses and exhibits a certain quality, property, or attribute. (reference *DoD M&S Glossary*)

Metric(s)

A process or algorithm that may involve statistical sampling, mathematical computations, and rule-based inferencing. Metrics provide the capability to detect and report defects within a sample. (reference *DoD M&S Glossary*)

Mission Space

The environment of entities, actions, and interactions comprising the set of interrelated processes used by individuals and/or organizations to accomplish assigned tasks. (reference *DoD M&S Glossary*)

Model

A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. (reference *DoD M&S Glossary*)

Modeling

Application of a standard, rigorous, structured methodology to create and validate a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. (reference *DoD M&S Glossary*)

Modeling & Simulation Resource Repository

The MSRR is a collection of Modeling and Simulation (M&S) resources. MSRR Resources include models, simulations, object models, Conceptual Models of the Mission Space (CMMS), algorithms, instance databases, data sets, data standardization and administration products, documents, tools and utilities. (reference www.msrr.dmso.mil/)

Modeling and Simulation

The use of models, including emulators, prototypes, simulators, and stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions. The terms “modeling” and “simulation” are often used interchangeably. (reference *DoD M&S Glossary*)

Modeling and Simulation Accreditation

See: Accreditation.

Model-Test-Model

An integrated approach to using models and simulations in support of pre-test analysis and planning; conducting the actual test and collecting data; and post-test analysis of test results along with further validation of the models using the test data. (reference *DoD M&S Glossary*)

Physical Prototype

A model whose physical characteristics resemble the physical characteristics of the system being modeled; for example, a plastic or wooden replica of an airplane. A mock-up. (reference *DoD M&S Glossary*)

Planning, Programming, and Budgeting System (PPBS)

The primary resource allocation process of DoD. One of three major decision making support systems for defense acquisition (the other two are the Requirements Generation System and the Acquisition Management System). It is a formal, systematic structure for making decisions on policy, strategy, and the development of forces and capabilities to accomplish anticipated missions. PPBS is a cyclic process containing three distinct, but interrelated phases: planning, which produces Defense Planning Guidance (DPG); programming, which produces approved program objectives memorandum (POM) for the military departments and defense agencies; and budgeting, which produces the DoD portion of the President's national budget. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Producibility

The relative ease of manufacturing an item or system. This relative ease is governed by the characteristics and features of a design that enables economical fabrication, assembly, inspection and testing using available manufacturing techniques. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Reliability

The ability of a system and its parts to perform its mission without failure, degradation, or demand on the support system. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Reliability Model

A model used to estimate, measure, or predict the reliability of a system; for example, a model of a computer system, used to estimate the total down time that will be experienced. (reference *DoD M&S Glossary*)

Risk

Risk is a measure of the inability to achieve a program's defined performance, schedule, and cost objectives, and has two components: 1) The probability of failing to achieve particular performance, schedule, or cost objectives; and 2) The consequence of failing to achieve those objectives. (reference *DSMC Acquisition Strategy Guide,* Third Edition)

SBA Pull

Those forces (attitudes, expectations, incentives, directives, policies, etc.), external to a program office, that influence a program office to adopt an SBA approach.

SBA Push

Those forces (attitudes, expectations, incentives, directives, policies, etc.), internal to a program office, that influence a program office to adopt an SBA approach.

Simulation Based Acquisition

An iterative, integrated product and process approach to acquisition, using modeling and simulation, that enables the warfighting, resource allocation, and acquisition communities to fulfill the warfighter's materiel needs, while maintaining Cost As an Independent Variable (CAIV) over the system's entire lifecycle and within the DoD's system of systems.

Solid Modeling

A digital representation of the surface characteristics of an object.

Stimulate

To provide input to a system in order to observe or evaluate the system's response. (reference *DoD M&S Glossary*)

Stimulation

The use of simulations to provide an external stimulus to a system or subsystem. An example is the use of a simulation representing the radar return from a target to drive (stimulate) the radar of a missile system within a hardware/software-in-the-loop simulation. (reference *DoD M&S Glossary*)

Supportability

The degree of ease to which system design characteristics and planned logistics for resources, including the logistic support elements, allows for the meeting of system availability and wartime utilization requirements. (reference *DSMC Glossary of Defense Acquisition Acronyms and Terms,* 8th Edition)

Synthetic Environment

Simulations that represent activities at a high level of realism, from simulations of theaters of war to factories and manufacturing processes. These environments may be created within a single computer or a vast distributed network connected by local and wide area networks and augmented by super-realistic special effects and accurate behavioral models. They allow visualization of and immersion into the environment being simulated. (reference *DoD M&S Glossary*)

System of Systems

Seamless connectivity of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) across the sea-land-space interface in a joint warfighting environment, and assimilation…into a coherent tactical picture…to develop a multi-dimensional netted architecture…while providing rapid sensor-to-shooter connectivity. (reference Admiral Jay Johnson, Chief of Naval Operations, during a visit to the Joint Strike Fighter program, 1995). The authors use the term System of Systems in a context broader than C4ISR, to encompass interactions between sub-systems of the same system, multiple system integration, user tradeoff analysis and optimization, and warfighting scenario optimization. One of the first places for the term System of Systems to show up in print was in the U.S. Naval Institute Proceedings May 1995 article "The Emerging System of Systems," by Admiral William A. Owens, US Navy. To the authors' knowledge, there is no commonly accepted definition of this term as yet.

Total Cost of Ownership

See: Total Ownership Cost (TOC).

Total Ownership Cost

The sum of all financial resources necessary to organize, equip, and sustain military forces sufficient to meet national goals in compliance with all laws; all policies applicable to DoD; all standards in effect for readiness, safety, and quality of life; and all other official measures of performance for DoD and its components. (reference *1998 Annual Report to the President and the Congress,* Office of the Secretary of Defense)

Validation

The process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation. (reference *DoD M&S Glossary*)

Verification

The process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification. Verification also evaluates the extent to which the model or simulation has been developed using sound and established software-engineering techniques. (reference *DoD M&S Glossary*)

Verification, Validation, and Accreditation

See each separate term.

Virtual

The essence or effect of something, not the fact. (reference *DoD M&S Glossary*)

Virtual Battlespace

The illusion resulting from simulating the actual battlespace. (reference *DoD M&S Glossary*)

Virtual Manufacturing

A model or simulation of the processes required for making an item.

Virtual Prototype

A model or simulation of a system placed in a synthetic environment, and used to investigate and evaluate requirements, concepts, system design, testing, production, and sustainment of the system throughout its lifecycle. (reference *DoD M&S Glossary*)

Virtual Reality

The effect created by generating an environment that does not exist in the real world. Usually, virtual reality is a stereoscopic display and computer-generated three-dimensional environment which has the effect of immersing the user in that environment. This is called the immersion effect. The environment is interactive, allowing the participant to look and navigate about the environment, enhancing the immersion effect. (reference *DoD M&S Glossary*)

Virtual Simulation

A simulation involving real people operating simulated systems. Virtual simulations inject human-in-the-loop in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team). (Note: Also see additional information under "Live, Virtual, and Constructive Simulation.") (reference *DoD M&S Glossary*)

Virtual World

See synthetic environment.

Visualization

The formation of an artificial image that cannot be seen otherwise. Typically, abstract data that would normally appear as text and numbers is graphically displayed as an image. The image can be animated to display time varying data. (reference *DoD M&S Glossary)*

War Game

A simulation game in which participants seek to achieve a specified military objective given pre-established resources and constraints; for example, a simulation in which participants make battlefield decisions and a computer determines the results of those decisions. Also used synonymously with constructive simulation. (reference *DoD M&S Glossary*)

Wargaming

The act of conducting a war game.

What-if Analysis

Analysis conducted to determine the impact of changing a variable during the design of a weapon system, as in “What if we change the stiffness of the beam, what will be the impact on the cost, schedule, and performance of the system?”

APPENDIX B

INTERVIEWS AND PERSONAL CONTACTS

APPENDIX B
INTERVIEWS AND PERSONAL CONTACTS

* SBA Industry Steering Group Member [1]
** Joint SBA Task Force Member[2]

COMPANY	CONTACT
ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV) PROGRAM OFFICE AAAV Technology Center USMC 991 Annapolis Way Woodbridge, VA 22191-1215	Richard Bayard Assistant Program Manager rbayard@notes.hqi.usmc.mil 703-492-3344 Mark Routson General Dynamics routsonm@gdls.com 703-492-3222
AERONAUTICAL SYSTEMS CENTER (ASC) Distributed Mission Training Office Wright Patterson Air Force Base, OH	Dr. Jerry Arnett arnettjb@asc-yw.wpafb.af.mil
AIR FORCE MATERIAL COMMAND Modeling and Simulation Integration Office Operating Location 12350 Research Parkway Orlando, FL 32826	Lt Col Joseph M. Terry** AFMC/MSIO-OL Liaison Officer terry.joe@afams.af.mil 407-208-5762
AIR FORCE RESEARCH LABORATORY 6001 S. Power Road, Bldg. 558 Mesa, AZ 85206-0904	Col Lynn Carroll, Chief Warfighter Training Research Division
ANSER 1215 Jefferson Davis Highway Arlington, VA 22202	Dr. Aron Pinker pinkera@anser.org 703-416-3439
APPLIED SYSTEMS INTELLIGENCE INC. 10882 Crabapple Road, Suite 2 Roswell, Georgia 30075	Norm Geddes President norm@asinc.com

COMPANY	CONTACT
ARMY SOFTWARE REUSE CENTER ASQB-IRC (Stop C-2) 6000 6th St, Suite S122A Ft Belvoir, VA 22060-5576	LTC Gene Glasser Director, ASRC glassere@issc.belvoir.army.mil 806-3860/4300
ASSISTANT SECRETARY OF THE ARMY (RESEARCH, DEVELOPMENT AND ACQUISITION), ASA(RDA) Attn: SARD-DO 103 Army Pentagon Washington, D.C. 20310	Lieutenant General Paul J. Kern Military Deputy to the ASA(RDA) 703-697-0356 Ellen Purdy** Senior Operations Research Analyst purdye@sarda.army.mil 703-604-7006 COL Michael Lavine lavinem@sarda.army.mil 703-604-7111 Dr. Herbert Fallin Director for Assessment and Evaluation fallinh@sarda.army.mil 703-697-2653 Mike Truelove** Acquisition Analyst Science Applications International Corporation (SAIC) truelovm@sarda.army.mil 703-604-7013 Paul Amos Acquisition Analyst Science Applications International Corporation (SAIC) amosp@sarda.army.mil 703-604-7003
ATACMS-BAT PROJECT OFFICE Army TACMS-BAT ATTN: SFAE-MSL-AB Redstone Arsenal, AL 35898-5650	COL John Holly hollyj@redstone.army.mil 205-876-1141

COMPANY	CONTACT
BALL AEROSPACE 8381 Old Courthouse Road Vienna, VA 22182	Larry Jobson ljobson@ball.com 703-917-9125
BARRONCAST, INC. 215 W. Oakwood Rd. P.O. Box 138 Oxford, Michigan 48371	Bruce Barron Vice President & General Manager Bruce@barroncast.com 248-628-4300 Lee Bennett Controller lee@barroncast.com 248-628-4300 Merlin Warner Sales Engineer Sales@barroncast.com
BOEING COMPANY Seattle, WA 98124	Larry Winslow. Director Technology for Phantom Works Michael W. Johnson* Defense & Space Group Vice-President Modeling & Simulation michael.w.johnson@boeing.com 253-773-3055
CACI 1600 Wilson Blvd Arlington, VA 22209-2515	Dr. Klaus Dannenberg Senior Vice President kdannenberg@hq.caci.com 703-558-0255
CARDEROCK NAVAL SURFACE WARFARE CENTER 9500 MacArthur Blvd West Bethesda, MD 20817-5700	Myles Hurwitz Head, Computer M&S Department NSWC/Carderock mhurwitz@oasys.dt.navy.mil (301)227-1927
CENTER FOR NAVAL ANALYSIS 4400 Ford Avenue Alexandria, VA 22302	Dr. Henry Eskew 703-824-2254

COMPANY	CONTACT
CHRYSLER CORPORATION 800 Chrysler Drive Auburn Hills, MI 48326-2757	Arthur Anderson Manager, Vehicle Engineering & Dimension Control Large Car Platform Greg Avesian Manager, Solutions Marketing gja1@chrysler.com 248-576-6676
CLOSE COMBAT ANTI-TANK WEAPON SYSTEM (CCAWS) PROJECT OFFICE SFAE-MSL-CC-TM Redstone Arsenal, AL 35898	John Bier Technical Manager Follow on to TOW Program john.bier@msl2.redstone.army.mil 256-842-0494 Allen Zumbach 256-876-3200
COLEMAN RESEARCH CORPORATION 6820 Moquin Drive Huntsville, AL 35806	Tim Thornton tthornton@hsv.crc.com 205-922-6000
COMANCHE PROGRAM OFFICE Redstone Arsenal, AL 35898	Dan Hollenbaugh Program Test Engineer 256-313-4464
COMPUTER SCIENCES CORPORATION China Lake, CA	Dennis Laack Joint Accreditation Support Activity (JASA) dlaack@csc.com 805-987-9641 x130

COMPANY	CONTACT
CRUSADER PROGRAM OFFICE SFAE-GCSS-CRE, Building 171 Picatinny Arsenal, NJ 07806-5000	Col Bill Sheaves Program Manager wsheaves@pica.army.mil 973-724-4588 Kevin Fahey Deputy Program Manager kfahey@pica.army.mil 973-724-4588 Jim Shields Chief of Systems Engineering jshields@pica.army.mil 973-724-7608
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA) 5201 Leesburg Pike, Suite 503 Falls Church, VA 22041	Gary Jones, Director Advanced Technology Integration gjones@darpa.mil 703-681-1484
DEFENSE INTELLIGENCE AGENCY Bolling Air Force Base Washington, D.C. 20340-5100	Richard Bernstein** Intelligence Officer bernstr@acq.osd.mil 703-820-1623

COMPANY	CONTACT
DEFENSE MODELING AND SIMULATION OFFICE 1901 N. Beauregard St Alexandria, VA 22311	Bruce Bailey DoD M&S Working Group bailey@dmso.mil 703-824-3420 Col Kenneth “Crash” Konwin konwin@dmso.mil 703-998-0660 Dr. Judith Dahmann jdahmann@msis.dmso.mil 703-998-0660 Jona McKee jmckee@msosa.dmso.mil 703-998-1637 John Gray Senior M&S Consultant jgray@msosa.dmso.mil 703-998-1623 Heikki Joonsar** hjoonsar@msis.dmso.mil 703-575-2452
DEFENSE SYSTEMS MANAGEMENT COLLEGE 9820 Belvoir Rd Fort Belvoir, VA 22060	Shane Donahue donahue_patrick@dsmc.dsm.mil 703-805-5411 Randy Zittel Professor Systems Engineering Zittelr@dsmc.dsm.mil 703-805-5267
DEPUTY CHIEF OF NAVAL OPERATIONS (LOGISTICS), OPNAV N4 Navy Pentagon 2000 Washington, DC 20350	Dan Fink, Deputy Acquisition Logistics Integration fink.dan@hq.navy.mil 703-601-1679

COMPANY	CONTACT
DEPUTY UNDERSECRETARY FOR DEFENSE, (INDUSTRIAL AFFAIRS & INSTALLATIONS), INDUSTRIAL CAPABILITIES AND ASSESSMENT 5203 Leesburg Pike, Suite 1403 Falls Church, VA 22041-3466	John D. Binford** General Engineer jbinford@acq.osd.mil 703-681-5472
DRAPER LABORATORY, INC. The Charles Stark 555 Technology Square Cambridge, MA 02139-3563	Dr James Negro jnegro@draper.com 617-258-3860 Moshe Cohen moshe@draper.com 617-258-4425
ELECTRIC BOAT CORP 75 Eastern Point Road Groton, CN 06340-4989	Gregory Angelini* Software Technology Team Leader, Computer Systems Technology John Porter CVX Principal Engr. jporter@ebmail.gdeb.com 860-433-7342 Jim Boudreaux jboudrea@ebmail.gdeb.com 860-433-6378
ELECTRONIC SYSTEMS COMMAND 5 Eglin St Hanscom AFB, MA 01731-2100	COL Hoot Gibson Director, Modeling, Simulation and Training PAD gibsonh@wg.hanscom.af.mil 781-377-6554
EVANS AND SUTHERLAND 12443 Research Parkway, Suite 303 Orlando, FL 32826	Paul Hinote phinote@es.com 407-658-1802

COMPANY	CONTACT
FOCUS: HOPE 1400 Oakman Blvd Detroit, MI 48238	Joe Petrosky General Manager Center for Advanced Technologies petrosky@exchange1.focushope.edu www.focushope.edu 313-494-4274
FORD MOTOR COMPANY 24500 Glendale Ave Detroit, MI 48239	Gene Coffman Staff Technical Specialist gcoffman@ford.com 313-592-2079 Hwa-Sung Na Principal Engineering Specialist hna@ford.com 313-592-2707
FORD MOTOR COMPANY 2000 Rotunda Drive Dearborn, MI 48121-2053	Michael Carty Product Development Center Mcarty@ford.com 313-317-9213 Richard Riff Advanced Engineering Center Manager C3P Project Office Rriff@ford.com 313-337-9670
GENERAL MOTORS 30200 Mound Road Warren, MI 48090-9010	David Chang, Director National Automotive Organization Vehicle Synthesis, Analysis & Simulation Process Center LNUSTC1.FZ9MR7@gmeds.com 810-986-6880 Prakash Shrivastava LNUSTC1.LZ1NYJ@gmeds.com 810-986-2206

COMPANY	CONTACT
HARVARD BUSINESS SCHOOL Soldiers Field Road Morgan Hall Boston, MA 0216	Professor Dorothy Leonard 617-495-6637 Stefan Thomke Assistant Professor sthomke@hbs.harvard.edu 617-495-6569 Ron Fox Professor Emeritus rfox@hbs.edu 315-655-4694
HEADQUARTERS DEFENSE INTELLIGENCE AGENCY Bolling AFB, MD	Richard Bernstein rbernste@MSIS.dmso.mil 202-231-8934
HIGH MOBILITY ARTILLERY ROCKET SYSTEM (HIMARS) 1411 Westview Drive Coralville, IA 52241	Mr. Brock Birdsong Mechanical Engineer, Missile RDEC birdsong-cb@redstone.army.mil 319-339-8755
IDA 1801 North Beauregard Street Alexandria, VA 22311-1772	Hans Mair Operational Evaluation Division mairh@asme.org 703-845-2034
INSTITUTE FOR SIMULATION TECHNOLOGY 3280 Progress Drive Orlando, FL 32826	Dr. Ronald Hofer, Ph.D. Associate Director rhofer@ist.ucf.edu 407-658-5576 Ernie Smart Director Governmental & Industrial Partnerships esmart@ist.ucf.edu 407-658-5014

COMPANY	CONTACT
INTEGRATION & TECHNOLOGY BATTLE LAB CDR, USATRADOC Attn: ATCD-B Ft Monroe, VA 23651-5000	Bob Dodd Military Analyst doddr@monroe.army.mil 757-727-5715
J.T. PARKER ASSOCIATES 3061 Mimon Road Annapolis, MD 21403-1317	Ted Parker* President; ADM (Ret) jparker@tecnet1.jcte.jcs.mil 301-261-1216
JOHN J. MCMULLEN ASSOCIATES, INC 2341 Jefferson Davis Hwy Arlington, VA 22202	Rob Beadling* Program Manager CVX Advanced Simulation rbeadling@jjma.com 703-418-4273
JOHNS HOPKINS UNIVERSITY 801 University Boulevard, SE Albuquerque, NM 87106	Dennis Lester dennis.lester@jhuapl.edu 505-853-1975
JOHNS HOPKINS UNIVERSITY Applied Physics Laboratory 11100 Johns Hopkins Road Laurel, MD 20723-6099	Dr. Mark Moulding Physicist mark.moulding@jhuapl.edu 240-228-4979 Glenn Gealy glenn.gealy@jhuapl.edu 2 40-228-6855 Jim Coolahan** SBA Task Force Technical Support James.coolahan@jhuapl.edu 240-228-5155 Bob Lutz** SBA Task Force Technical Support Robert.lutz@jhuapl.edu 240-953-5000

COMPANY	CONTACT
JOINT SIMULATION SYSTEM (JSIMS) Orlando, FL	Dave Walker Analysis and Integration Manager david_walker@jsims.com 407-384-2909, ext. 738
JOINT STRIKE FIGHTER PROGRAM OFFICE 1745 Jeff Davis Hwy, Suite 307 Arlington, VA 22202	COL Phil Faye Director, Requirements (RQ) fayepa@jast.mil 703-602-7390 x6649
KROUSE ASSOCIATES 7310 Holly Park Dr. Concord, OH 44060	John Krouse jkrouse@compuserve.com 440-354-5334
LOCKHEED MARTIN Washington Operations 1725 Jefferson Davis Highway Arlington, VA 22202-4127	A.J. (Beau) Beauregard, P.E.* Director, Advanced Programs Aeronautics Sector beau.beauregard@lmco.com 703-413-5711
LOCKHEED MARTIN PO Box 748 Fort Worth, TX 76101	Linda Poole Program Manager Virtual Product Development Initiative (VPDI) 817-763-2096
LOCKHEED MARTIN AERONAUTICAL SYSTEMS 86 South Cobb Drive Marietta, GA 30063	Margaret Herald* margaret.s.herald@lmco.com 770-494-9833
LORAL/LOCKHEED MARTIN FEDERAL SYSTEMS 546 Lob Lolly Dr Woodlake, NC	LTG (Ret) Dan Schroeder Consultant Frigate120@aol.com 910-245-3136
MICROSOFT One Microsoft Corporation Redmond, WA 98052-6399	Mark Walker markwalk@microsoft.com 425-703-3181

COMPANY	CONTACT
MITRE 11493 Sunset Hills Rd Reston, VA 20190	Marvin Hammond mhammond@mitre.org 703-883-5867 Stuart Starr starr@mitre.org 703-883-5494
MULTIGEN, INC. 6701 Democracy Blvd Bethesda, MD 20817	Bill MacKrell N.E.Regional Sales Representative bmackrell@multigen.com 301-571-2466
MULTIGEN, INC. 550 S. Winchester Blvd San Jose, CA 95128	Ray Homan Exec. V. President and Gen. Manager rhoman@multigen.com 408-261-4100
NAVAL COASTAL SYSTEMS STATION Panama City, FL	Roger Leete leete_roger@ccmail.ncsc.navy.mil 850-234-4265
NAVAL RESEARCH LABORATORY 4555 Overlook Avenue, SW Washington, D.C. 20375	Bill Sandberg Deputy Director, Laboratory for Computational Physics and Fluid Dynamics sandberg@lcp.nrl.navy.mil 202-767-0526
NAVAL SEA SYSTEMS COMMAND (NAVSEA) 2541 Jefferson Davis Hwy Alexandria, VA 22242-5610	Mike Rice O3KQ rice_mike_l@hq.navsea.navy.mil 703-602-0887, ext. 327 Stuart Marcus** 05K11 marcus_stuart_j@hq.navsea.navy.mil 703-602-7242, ext. 107

COMPANY	CONTACT
NAVAL SURFACE WARFARE CENTER Port Hueneme Division Building 1380 4363 Missile Way Port Hueneme, CA 93043-4307	Joe Stelling** SBA Task Force Leader 805-228-8719
NAVAL UNDERSEA WARFARE CENTER 1176 Howell St Newport, RI 02841	Jeff Feaster Engineering ,T&E Dept feasterjt@npri70.npt.nuwc.navy.mil 401-841-6892 x22314 Debra Jones Electronics Engineer Capital Purchase Program Manager 401-841-2012 x 23351 Tom Kowalczyk kowalczyktw@code80.npt.nuwc.navy.mil 401-841-6892
NAVY M&S MANAGEMENT OFFICE Crystal City Presidential Towers Arlington, VA 22202	CAPT Jay Kistler kistler.jay@hq.navy.mil 703 601-1482
NAVY MODELING AND SIMULATION MANAGEMENT OFFICE N6M1	George Phillips Navy M&S Point of Contact phillips.george@hq.navy.mil 703-685-6995
NEWPORT NEWS SHIPBUILDING 4101 Washington Ave Newport News, VA 23607-2770	Wayne Evans Manager, Lifecycle Engineering evans_wa@nns.com 757-380-4876 Dan Selfridge Lifecycle Engineering selfridge_dj@nns.com 757-688-6335

COMPANY	CONTACT
NORTHROP GRUMMAN 8900 East Washington Blvd Pico Rivera, CA 90660	Rahim Munshi Systems Engineer rahim_munshi@email.northgrum.com 562-948-8824
NSSC, SC-21 PROGRAM 2531 Jefferson Davis Hwy Arlington, VA 22242	Janet Jaensch Director, SC-21 Modeling & Simulation jaensch_janet@hq.navsea.navy.mil 703-602-6453, x 105 Thien Ngo Asst. Director, Modeling and Simulation ngo_thien_c@hq.navsea.navy.mil 703-602-6453, x 122
OCI, INCORPORATED 1235 Jefferson Davis Highway Arlington, VA 22202	Donald Hirsch dhirsch@oc-inc.com 703-416-0002
OPTIMETRICS, INC. (OMI) 1 Newport Drive Forest Hill, MD 21050	Frank Wysoki* wysoki@omi.com 703-791-2286
ORIGINAL SIM 5524 St. Patrick Montreal, Canada H4E 1A8	Christian Rochefort Regional Sales Manager crochefort@originalsim.com 514-766-8868
PLYNETICS EXPRESS 1067 Centre Road Auburn Hills, MI 48326	Rick Hannan Project Manager Rhannan@plynex.com 248-373-4400 Steven Willis Program Manager swillis@plynex.com

COMPANY	CONTACT
PONTIAC-GENERAL MOTORS CORP. 100 Renaissance Center Detroit, MI 48243-7301	Ronald Strayhorn Vice President, Sales and Service rstrayhorn@pmd72.hbs.edu 313-667-4132
PROGRAM EXECUTIVE OFFICER THEATER AIR DEFENSE (TAD) PEO TAD, NAVSEA Crystal City Arlington, VA	Lorraine Shea Director M&S, PEO TAD, NAVSEA Shea_Lorraine@hq.navsea.navy.mil
RAYTHEON ELECTRONIC SYSTEMS 1001 Boston Post Rd Marlboro, MA 01752	William Stewich Mgr. Business Dev. C4I Programs william_stewich@ccmail.res.ray.com 508-490-3228
RAYTHEON SYSTEMS COMPANY Plano, TX 75086	Randy Boys* rboys@rtis.ray.com 972-575-6128
RAYTHEON SYSTEMS COMPANY 7700 Arlington Blvd Falls Church, VA 22204	Steve Olson* steve_olson@fallschurch.esys.com 703-876-1942
RL ENGWALL & ASSOCIATES 560 Choptank Cove Court Annapolis, MD 21401	Dick Engwall* Management Consultant rlengwall@aol.com 410-571-8623
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC) 8301 Greensboro Dr., Suite 290 McLean, VA 22102	Annie Patenaude anne.m.patenaude@cpmx.saic.com 703-749-5109

COMPANY	CONTACT
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC) 2511 Jefferson Davis Highway Arlington, VA 22202-3911	Tom Brown f.thomas.brown@cpmx.saic.com Dave Thomen thomend@mail.etas.com 703-414-0189
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION (SAIC) 3045 Technology Parkway Orlando, FL 32826-3299	Col (Ret) James Shiflett Vice President 407-207-2725 W. San Horton Senior Technical Manager 407-282-6700
SECRETARY OF THE AIR FORCE 1060 Air Force Pentagon Washington, DC 20301	Lieutenant General George Muellner Principal Deputy (Acquisition) 703-695-7311 MAJ Gary Hopper SAF/AQPS hopperg@af.pentagon.mil 703-588-7171 MAJ Gerald S. Smither, Jr.** SAF/AQIK smitherg@af.pentagon.mil 703-588-7191 Lt. Col Paul W. Coutee** SAF/AQRE couteep@af.pentagon.mil 703-588-5757

COMPANY	CONTACT
SIMULATION TRAINING AND INSTRUMENTATION COMMAND (STRICOM) 12350 Research Parkway Orlando, FL 32826	Stan Goodman goodmans@stricom.army.mil Donald Jones Deputy Product Manager, Air & Combat Training Systems jones1@stricom.army.mil 407-384-5142 Les Curless les_curless@stricom.army.mil 407-384-3860 Dr. Stuart Olson stuart_olson@stricom.army.mil 407-384-5132 Admiral Piper pipera@stricom.army.mil 407-384-3935 Phillip Sprinkle Deputy PM Training Devices sprinklp@stricom.army.mil 407-384-5202 Ed Trier triere@stricom.army.mil 407-384-3800 Bill Blanding blandinb@stricom.army.mil 407-384-5118
SPACE & WARFARE SYSTEMS COMMAND (SPAWAR) 4301 Pacific Hwy C60 Topside San Diego, CA 92110-3127	Phillip Hornick Deputy Program Manager M&S hornickp@spawar.navy.mil 619-537-0145

COMPANY	CONTACT
SPACE AND MISSILE SYSTEMS CENTER 180 Skynet Way Los Angeles Air Force Base, CA 90245	Mark Fagan Chief, Modeling & Simulation Division Directorate of Developmental Planning mark.fagan@losangeles.af.mil 310-363-2461
STANFORD RESEARCH INSTITUTE (SRI) INTERNATIONAL 333 Ravenswood Avenue Menlo Park, CA 94025	Ralph Toms Senior Technical Advisor ralph_toms@sdd.sri.com 650-859-2852
STANFORD RESEARCH INSTITUTE (SRI) INTERNATIONAL 1611 North Kent Street Arlington, VA 22153	Greg Wilcox* wilcox@sri.com 703-247-8467
TECHNICAL AUTOMATION SERVICES CORPORATION (TASC) 55 Walkers Brook Dr Reading, MA 01867	Murray Cantor Program Management mrcantor@tasc.com 617-942-2000 Hal Jones* Technical Automation Services Corporation (TASC) 55 Walkers Brook Drive Reading, MA 01867-3297 hljones@tasc.com 617-942-2000 x 2207
THE UNIVERSITY OF MICHIGAN College of Engineering 2236 G.G. Brown Building Ann Arbor , MI 48109-2125	Panos Papalambros Professor and Chair Mechanical Eng. & Applied Mechanics http://www-personal.engin.umich.edu/~pyp/ 734-764-8464

COMPANY	CONTACT
TRAINING AND DOCTRINE COMMAND Systems Manager for Cannon Systems Commandant U.S. Army Field Artillery School (USAFAS) Ft Sill, OK 73503-5600	COL Michael Cuff TRADOC Sys. Mgr for Cannon Systems cuffm@usafas.army.mil 580-442-6902
TRIDENT SYSTEMS INC. 10201 Lee Highway Suite 300 Fairfax, VA 22030	Nick Karangelen* President nkarang@tridsys.com 703-691-7765
U.S. ARMY DIRECTOR OF INFORMATION SYSTEMS FOR COMMAND, CONTROL, COMMUNICATIONS & COMPUTERS (DISC4) Pentagon 3E458 Washington, DC 20301	COL James Deal Executive Officer dealjc@hqda.army.mil 703-697-5503
U.S. ARMY LOGISTICS MANAGEMENT COLLEGE Attn: ATSZ SAM PQMD Bldg. 12500 2401 Quarters Rd Fort Lee, VA 23801-1705	Dr. George Huntley HUNTLEYG@LEE-DNS1.ARMY.MIL 804-765-4265
U.S. ARMY MATERIAL SYSTEMS ANALYSIS ACTIVITY AMXSY-CA 392 Hopkins Road Aberdeen Proving Grounds, MD 21005-5071	Patrick O'Neill Chief, C4I Branch Will Brooks A2ATD Program Office Chief, Simulation Branch Wbrooks@arl.mil 410-278 – 4946
U.S. ARMY MATERIAL SYSTEMS ANALYSIS ACTIVITY (AMSAA) Attn: AMXSY-A Rock Island, IL 61299-7260	Jerry Moeller Gmoell@ria-emh2.army.mil 309-782-7823

COMPANY	CONTACT
U.S. ARMY MODELING AND SIMULATION OFFICE DAMO-ZS 1111 Jefferson Davis Hwy Crystal Gateway North Arlington, VA 22202	Linda Stone Stonell@hqda.army.mil 703-601-0010, x 33 William Dunn Dunnwih@hqda.army.mil 703-601-0011 x 25
U.S. ARMY TANK AND AUTOMOTIVE COMMAND USATACOM TARDEC Warren, MI 48397 – 5000	Arthur Adlam Attn: AMSTA-TR-VP Adlama@cc.tacom.army.mil 810-574-8882 Tim Bailey Attn: AMSTA-TR-N/002 Baileyt@tardec.tacom.army.mil 810-574-5074 Jerry Chapin Chapinj@cc.tacom.army.mil 810-574-6144 David Holm Operations Research Analyst holmd@cc.tacom.army.mil 810-574-6537 Paul Skalny National Automotive Center skalnyp@cc.tacom.army.mil 810-574-5436

COMPANY	CONTACT
U.S. ARMY TEST & EVALUATION COMMAND Aberdeen Proving Ground, MD 21005	Dave Brown cdbrown@tec1.apg.army.mil 410-278-1473 John Haug jhaug@tec1.apg.army.mil 410-278-1275 LTC Skip Paul wpaul@tec1.apg.army.mil 410-279-1480
U.S. ATLANTIC COMMAND Joint Training, Analysis and Simulation Center (JTASC) 116 Lakeview Pkwy Suffolk, VA 23435-2699	Lt. Col Robert Strini Chief, Synthetic Theater of War (STOW) Branch strini@acom.mil 757-686-7525
UNDER SECRETARY OF DEFENSE ACQUISITION TECHNOLOGY, USD(A&T) Pentagon Washington, DC 20301	Honorable Jacques S. Gansler 703-695-2381 Dave Oliver Principal Deputy oliverdr@acq.osd.mil 703-697-7017
UNITED DEFENSE LIMITED PARTNERSHIP (CRUSADER PROGRAM) 4800 East River Road Minneapolis, MN 55421-1498	Richard Staiert Project Manager Advanced Systems Development dick_staiert@udlp.com 612-572-4815 Bob Stratton Business Development Manager robert_stratton@udlp.com 612-572-6257 Steven Untz Crusader Information Mgmt. Manager steve_untz@udlp.com 612-572-7946

COMPANY	CONTACT
UNITED DEFENSE LIMITED PARTNERSHIP (CRUSADER PROGRAM) (continued) 4800 East River Road Minneapolis, MN 55421-1498	David Wallestad Crusader Program Director dave_wallestad@udlp.com 612-572-4799
UNITED DEFENSE LIMITED PARTNERSHIP 12443 Research Pkwy Orlando, FL	Warren Richeson Director 407-380-5500 Bob Hatton Manager, Orlando Ops Training Systems Group bob_hatton@udlp-orl.com 407-380-5500
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN Urbana, IL 61801	Wayne J. Davis Professor General/Mechanical & Industrial Eng. w-davis@uiuc.edu 217-333-0531
UNIVERSITY OF IOWA The University of Iowa Dept of Mechanical Engineering Iowa City, IA 52241	Dr. Edward Haug haug@nads-sc.uiowa.edu 319-335-5726
VECTOR RESEARCH, INC P.O. Box 1506 Ann Arbor, MI 48106	Peter Cherry Cherryw@vrinet.com 734-973-9210

1. The SBA Industry Steering Group (ISG) is industry's primary interface with DoD regarding SBA. The ISG is endorsed by the National Defense Industrial Association (NDIA), the International Council on Systems Engineering (INCOSE), the National Training Systems Association, the Aerospace Industries Association (AIA), the Institute of Electrical and Electronics Engineers (IEEE) and the Electronic Industries Association (EIA). Members below are identified with a *.

2. The Joint SBA Task Force is discussed in Chapter 3, Background. Members below are identified with a **.

APPENDIX C

ABOUT THE AUTHORS

APPENDIX C
ABOUT THE AUTHORS

LTC Michael V.R. Johnson, Sr., US Army, has over 20 years of operational and acquisition experience. His most recent assignment was with Headquarters, Army Special Operations Command as Acquisition Branch Chief. Other acquisition assignments include: Maintenance Engineer with Communications and Electronics Command; Training with Industry at Martin Marietta; Project Director at Simulation Training and Instrumentation Command (STRICOM); and the first Project Director for the Distributed Interactive Simulation Office. LTC Johnson's operational assignments include: aviation assignments in Fulda, Germany with the 11th Armored Cavalry Regiment, at Fort Carson, Colorado with the 4th Infantry Division as a Company Commander in the Aviation Brigade, Brigade Plans Officer for a Mechanized Infantry Brigade; and as the Operational Aviation Officer for the 4th Division, and at Fort Knox as a Cavalry Platoon Leader with the 2/6 Cavalry Brigade. LTC Johnson has a Masters Degree in Contract Acquisition Management and is a graduate of the U.S. Military Academy, the Harvard Graduate School of Business's Program for Management Development, the Army's Command and General Staff College, and the Defense Systems Management College's Advanced Program Manager's Course. He is rated in the OH-58, AH-1 and UH-1 helicopters. He is also Airborne and Ranger qualified.

LtCol Mac McKeon, US Marine Corps, has 20 years of aviation service, flying the F-4 Phantom, A-6 Intruder, and the F/A-18 Hornet. His most recent assignment was as the Operations Officer, Marine Aircraft Group-31 at MCAS Beaufort, SC. LtCol McKeon began his acquisition career as the Program Manager for the USMC Land and Training Area Requirement System at the Defense Training and Performance Data Center in Orlando, FL. Subsequent acquisition assignments include Project Manager for USMC/USN KC-130 Flight Simulators and as Program Manager for USMC and DoD Virtual Reality R&D programs at the Naval Air Warfare Center Training Systems Division, Orlando, FL. LtCol McKeon graduated from the U.S. Naval Academy in 1978 with a B.S. in Political Science. He received his M.S. in Computer Systems Management/Information Technology in 1991 from the Naval Postgraduate School, Monterey, CA. He is a graduate of the Harvard Graduate School of Business's Program for Management Development, the USMC Amphibious Warfare School, and the Marine Command and Staff Course.

Lt Col Terence R. Szanto, US Air Force, has 13 years of acquisition experience at the program office, Air Staff, joint, and international levels. He was most recently assigned to Headquarters Air Force, providing recommendations for $24 billion of the $450 billion Air Force Future Years Defense Plan. In a joint acquisition assignment in the Republic of Korea, he coordinated military technology cooperation programs. At the Electronic Systems Center, Hanscom AFB, he upgraded the B-1 and B-52 aircraft mission planning systems for smart and conventional weapons capabilities, and maintained 238 tactical aircraft mission planning systems deployed at 150 locations worldwide. His first acquisition assignment was at Space Division, Los Angeles AFS, CA. Lt Col Szanto spent a career broadening assignment in F4-E aircraft maintenance at George AFB, CA. He graduated from the U.S. Air Force Academy in 1981 with a B.S. in Engineering Mechanics, and received an MBA from Pepperdine University. Lt Col Szanto is a graduate of the Harvard Graduate School of Business's Program for Management Development, is a distinguished graduate of Squadron Officers School and Air Command and Staff College, and will attend the Industrial College of the Armed Forces this fall.

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